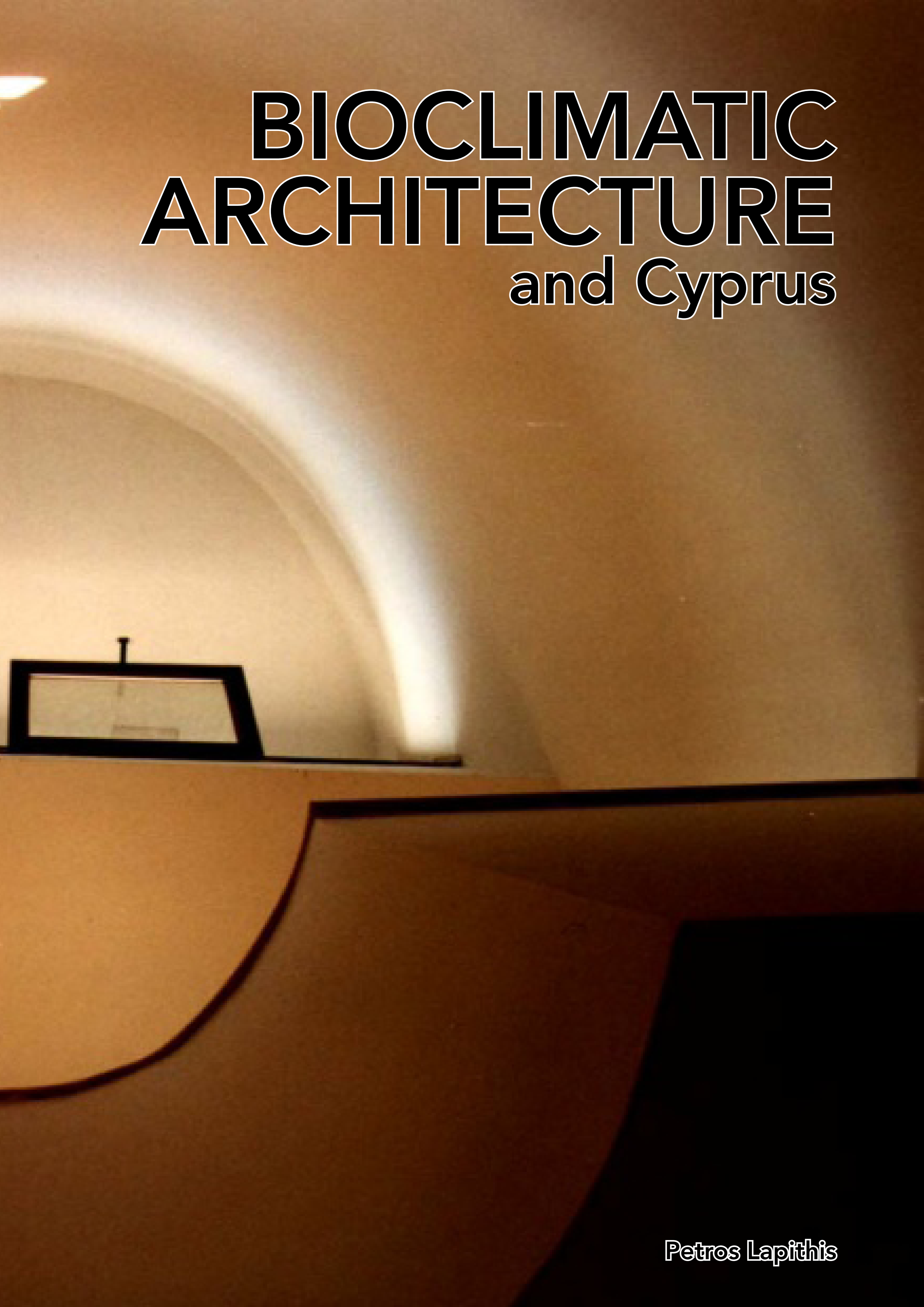
BIOCLIMATIC ARCHITECTURE
and Cyprus



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His research interests include sustainable design, issues of quality of life, energy conservation, bioclimatic architecture and solar energy design. His research work has been supported by various research grants and has been published in International Conference Proceedings and Journals as well as other media. Lapithis has also participated in EU programmes such as COST C16 project "Improving the quality of existing urban building envelopes" and COST C23 project "Strategies for a Low Carbon Built Environment project".

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Preface and Acknowledgements

"Bioclimatic Architecture and Cyprus" sets out to demonstrate that bioclimatic architecture is a viable energy-saving concept which can be applied in the context of Cyprus through both research and hands on examples. A principal aim of the research revealed in this publication was to develop an understanding of the criteria needed for an appropriate bioclimatic architecture that is sensitive to both energy use and climatic conditions.

For this purpose, the climatic conditions Cyprus, thermal comfort, passive solar systems, comparison of vernacular and contemporary buildings, energy uses, building and energy legislations, education in bioclimatic architecture and building examples (academic and professional) were studied, concluding that passive solar design may be successfully applied through the design of modern buildings in Cyprus.

A crucial argument that transpires from this research is whether environmentally responsible architecture should be regarded as a specialisation within architectural education or whether the entire spectrum of architecture should be taught as a science and as an art that is equally accountable to man and to the environment. This begs the question: Shouldn't architecture always be ecologically responsible?

This book brings local case studies to the forefront in an attempt to give a concrete understanding on bioclimatic architecture. It entails of a compilation of student design projects from the Department of Architecture, of the University of Nicosia as well as built projects by the author which address bioclimatic design approaches.

I would like to extend my appreciation by acknowledging the contribution of all students who have participated in the various courses that I have taught on various aspects of Bioclimatic Architecture such as the Sustainable Design course, the Space and Light course, the Bioclimatic Architecture course, the Energy Efficient Buildings course, the Sustainable Design Unit and the Design for Diversity Unit from the first years of its inception.

Deep appreciation is extended to Dr Anna Papadopoulou for her stimulating interest and valuable advice throughout my work, and for extending her valuable knowledge and time to assist in my research. To Melissa Hekkers for her personal input and proofreading of the book. I also wish to thank my family, my daughter Lara, my colleagues (practicing and academic) and my friends for a lifetime of support and friendship, without whose love, understanding and moral support, this work might never have been completed.

This book is dedicated to designers of buildings, every single one of whom, from student to senior partner, have an important role to play in the reduction of energy consumption in buildings around the world. The goal of this book is to transcend knowledge without any monetary benefit. The book is available for free.

*"**Bioclimatic architecture** refers to the design of buildings and spaces (interior – exterior – outdoor) based on local climate, aimed at providing thermal and visual comfort, making use of solar energy and other environmental sources. Basic elements of bioclimatic design are passive solar systems which are incorporated onto buildings and utilise environmental sources (for example, sun, air, wind, vegetation, water, soil, sky) for heating, cooling and lighting the buildings" (CRES, 2017).*

*"**Passive solar systems** are the integrated parts – elements of a building which function without mechanical parts or additional energy supply and are used for heating as well as cooling buildings naturally. Passive solar systems are divided into three categories: Passive Solar Heating Systems, Passive (Natural) Cooling Systems and Techniques, Systems and Techniques for Natural Lighting" (CRES, 2017).*

*"**Green building** (also known as green construction or sustainable building) refers to both a structure and the application of processes that are environmentally responsible and resource-efficient throughout a building's life-cycle: from planning to design, construction, operation, maintenance, renovation, and demolition (Wikipedia, 2017).*

*"**Sustainable architecture** seeks to minimize the negative environmental impact of buildings by efficiency and moderation in the use of materials, energy, and development space and the ecosystem at large. Sustainable architecture uses a conscious approach to energy and ecological conservation in the design of the built environment" (Wikipedia, 2017).*

*"**Solar architecture** is an approach that takes in account the sun to harness clean and renewable solar power. It is related to the fields of optics, thermics, electronics and materials science. Both active and passive solar housing skills are involved in solar architecture". (Wikipedia, 2017)*

Contents

OVERVIEW OF CYPRUS

Introduction

Cyprus is the third largest island (covering only 9.251 km^2)in the Mediterranean, found at the crossroads of Europe, Asia and Africa. The Mycenaean and the Achaean brought their civilisation to the island over 3,000 years ago. Many others passed through, including the Phoenician, Assyrian, Egyptians, Persians, Romans, Crusaders, Venetians, Ottomans and British. Prehistoric settlements, ancient Greek temples, Roman theatres and villas, early Christian basilicas, Byzantine churches and monasteries, Crusader castles, Gothic churches and Venetian fortifications can be witnessed across the island.

Figure 1.1. Map of the Mediterranean (Google Maps, 2017)

The island gained its independence in 1960 and was proclaimed a Republic. During the period 1960-73 Cyprus went through a fast and almost uninterrupted growth. Despite a breakdown due to the Turkish invasion, in 1974 and the occupation of 38% of its territory by military forces, the economy recovered soon after and a substantial growth was achieved. From 1975-1993, Cyprus once again witnessed additional economic growth, accompanied by an expansion of social services. Today the people of Cyprus who live in the Government controlled area of the country, enjoy a high level of education, low unemployment and a good standard of health care. Crime is maintained at low levels. 69% of the population lives in urban areas which cover 9.6% of the island. By the 1st of May 2004, Cyprus became a full member-state of European Union.

Every building has different values, problems and on occasion, heritage (Nomikos, 2004). From a thermal environment standpoint, each inhabited building complex in Cyprus falls under one of the following categories:

1. The climate is totally ignored. The claim is that a climate sensitive design is not required because the climate extremes are not severe.

2. Only winter conditions are considered. The idea is to minimise the heating requirements in order to save fuel and ignore the problem of overheating summer.

3. The climatic constraints influence the design of houses.

Generally, the third design option is found in vernacular houses throughout the country but contemporary houses always seem to be built either to ignore the climate or, in the best of cases, consider the winter conditions only, and provide an inadequate shading arrangement for the summer.

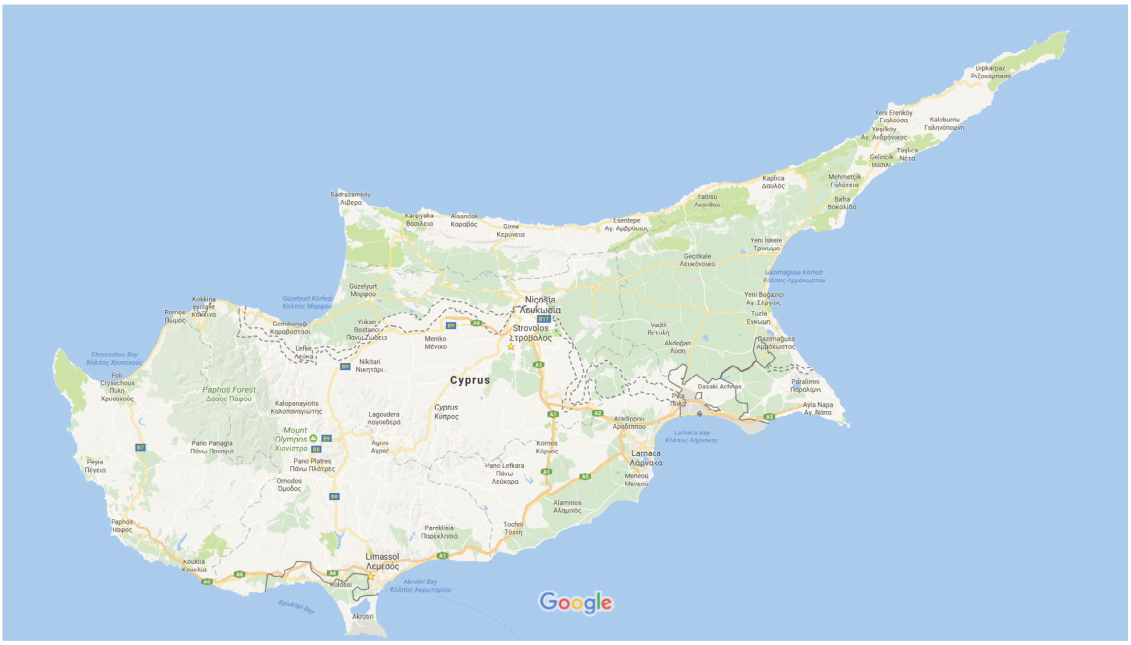


Figure 1.2. Map of Cyprus (Google Maps, 2017)

In an attempt to evaluate some of the current housing habits in Cyprus, a questionnaire was compiled (Lapithis 2003). The results of the questionnaire were taken from contemporary residential buildings, with mostly four or five residents, in urban areas of Nicosia. From the outcome of the questionnaire, it transpired that most dwellings in Cyprus are constructed with little or no insulation and this is the most likely cause for the high percentage of summer and winter discomfort as well as noise complaints. Most other complaints stated (e.g. poor natural lighting) are the result of unsuccessful bioclimatic orientated design. All this suggests the need for better, more bioclimatic appropriate constructions, with adequate insulation and proper orientation with respect to the sun.

The research was focused on the residential sector because increased energy efficiency in residential buildings is still regarded as a 'new' field. It also assists the government's aim to comply with the EU energy regulations, due to the present challenges Cyprus is facing with its accession to the European Union.

The research also set out to demonstrate that passive solar architecture is a viable energy-saving concept which can be applied in the context of Cyprus. A principal aim of the research was to develop an understanding of the criteria needed for an appropriate

passive solar architecture that is sensitive to both energy use and climatic conditions. Through the research the following parameters were studied:

- The climate of Cyprus
- The comfort zone of the average Cypriot
- Examples of historical and traditional housing which can be shown to inform passive solar architecture in Cyprus
- The energy uses of the island
- Building and energy legislations

The results of these studies show that passive solar design is an appropriate energy-saving strategy for Cyprus. Monitoring the Experimental Solar House led to various conclusions regarding its performance as well as indications for further development and improvement.

Climatic Conditions in Cyprus

Taking local climatic conditions into consideration, the significance of design (Konya, 1980) is essential in order to employ the appropriate strategies for the design and selection of the most suitable passive solar systems. Stein (Stein, 1977) addresses two viewpoints. Firstly, that respect for the climate is firmly tied to the aim of conserving energy by building design. And secondly, a building that is designed to exclude and ignore site and climate would be completely irrelevant with its surroundings.

The principal climatic elements, with regard to human comfort and building design, are solar radiation, temperature, humidity, wind, precipitation and other such specific characteristics. Bioclimatic architecture, indeed any architecture, cannot persist without being as site-specific as possible, especially in an island like Cyprus where bioclimatic design can be the best solution for the design of energy efficient buildings (Lapithis,1994) (Lapithis, 2003). Climate is one of the ultimate site-specification criteria, while it is important to note that human activities have the potential of changing climate.

Cyprus has an intense Mediterranean climate with a typical seasonal rhythm concerning temperature, rainfall and weather in general. The central Troodos massif, rising to 1951 metres and, to a lesser extent, the long narrow Pentadaktylos mountain range, with peaks of about 1,000 metres, play an important part in the meteorology of Cyprus. The predominantly clear blue skies and high sunshine periods give large seasonal and daily variations between the temperature of the coast and the interior of the island that also cause considerable climate change effects, especially near the coasts.

Its average hottest peak reaches 41°C in the summer and drops to an approximate of 5°C in the winter. Relative humidity ranges from 40-60%, and a large daily temperature range is noted with up to 18°C difference between day and night. Thus Cyprus's climate

calls for the need of cooling in the summer, and the large amount of solar radiation during the summer may easily be used for heating in winter.

In summer the island is mainly under the influence of a shallow trough of low pressure extending from the great continental depression centred over Southwest Asia. It is a season of high temperatures with almost cloudless skies. Rainfall is almost negligible but isolated thunderstorms sometimes occur. Thus the rainfall estimates to less than 5% of the total in the average year.

In the winter months Cyprus is near the track of fairly frequent small depressions that cross the Mediterranean Sea from west to east between the continental anticyclone of Eurasia and the overall low-pressure belt of North Africa. These depressions give rise to periods of disturbed weather usually lasting from one to three days and produce most of the annual precipitation, the average fall from December to February being about 60% of the annual total.

Snow occurs rarely in the lowlands and on the Kyrenia range, however snow falls frequently every winter on ground above 1,000 metres. This snowfall occurs usually by the first week of December and ends by the middle of April. Although snow cover is not continuous during the coldest months it may lie to considerable depths for several weeks especially on the northern slopes of the highest Troodos peaks (Meteorological Services, 1993).

The climate of Cyprus can be summarised as:

- Cyprus is within the Mediterranean temperate zone
- Hot summers rise to an approximate of 41°C in its warmest month
- Mild winters drop to an approximate of 5°C in its coldest month
- Average humidity of 40-60% (sustaining within the comfort zone limits)
- Large daily temperature range (up to 18°C difference between night and day)
- The large amount of solar radiation which varies from 3.48 KWh/m^{2}day in midwinter to 8.82 KWh/m^{2}day in midsummer, result in the potential for solar energy usage in winter
- The predominantly clear blue skies and high sunshine periods give large seasonal and daily variations between the temperature of the coast and the interior of the island that also cause considerable climate change effects especially near the coasts
- At Latitude 35° North, Longitude 33° East, Cyprus has a day length of 9.8 hours in December to 14.5 hours in June
- Snow falls frequently every winter on ground above 1,000 metres. Usually during the first week of December and ends by the middle of April

Climatic Zones

The climatic zones are valid for both the heating and the cooling period (Meteorological Service, 1993).

Climatic zones	Cumulative temperatures for heating periods <20^{0}C	Heating period <20^{0}C (months)	Cooling period <20^{0}C (months)	Mean Temperature for heating period (^{0}C)	Mean temperature for cooling period (^{0}C)
Z1 Coastal areas	26667	6	4	14.2	25.8
Z2 Flat areas in the interior	32739	6	4	13.2	27.2
Z3 Semi-mountain areas	40439	6	4	12.6	26
Z4 Mountain areas	64278	8	2	11.6	25.2

Table 1.1 Climatic Zones of Cyprus (Meteorological Service, 1993)

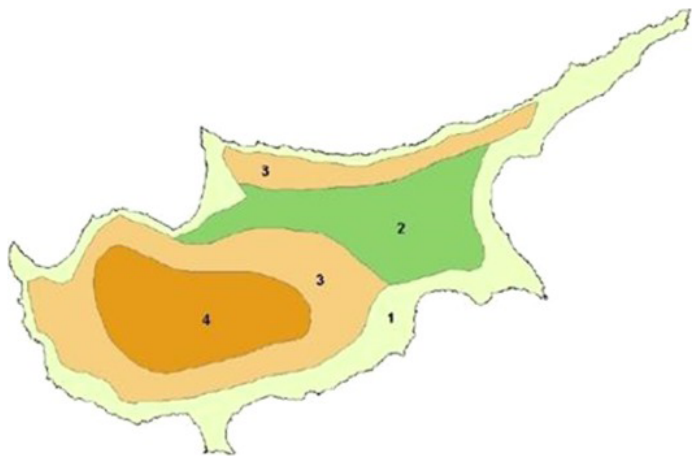


Figure 1.3 Climatic zones (Meteorological Service, 1993)

Air Temperatures

Cyprus experiences hot summers and mild winters, but this generalisation must be modified by the consideration of altitude, which lowers temperatures by about 5°C per 1,000 metres and that of marine influence, giving cooler summers and warmer winters adjacent to most of the coastlines and especially along the west coast (Meteorological Services, 1993). The seasonal difference between mid-summer and mid-winter is quite large, at 18°C inland and about 14°C on the coasts.

Maximum temperature differences between day and minimum temperatures at night are

also quite large, especially inland during the summer. In winter these differences are 8 to 10°C on the lowlands, and 5 to 6°C on the central plain and 9 to 12°C elsewhere.

In July and August the mean daily temperature ranges between 29°C on the central plain and 22°C on the Troodos mountains, while the average maximum temperature for these months ranges between 36°C and 27°C respectively. In January the mean daily temperature is 10°C on the central plain and 3°C on the mountains respectively.

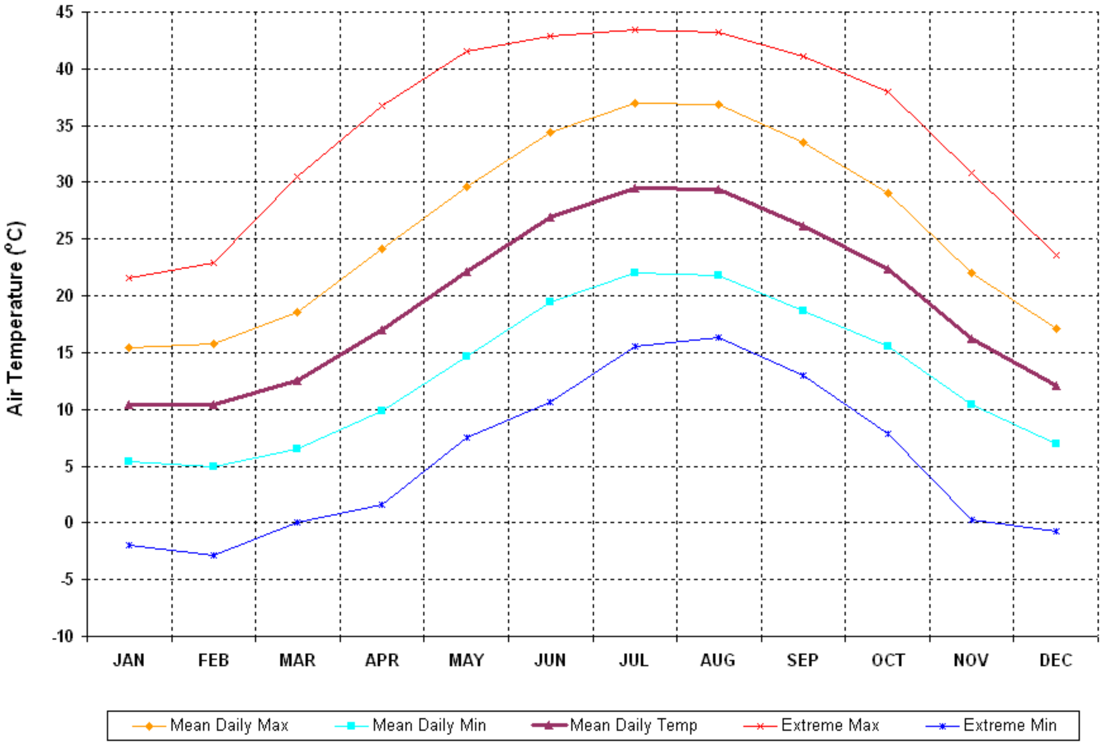


Figure 1.4 Monthly variation of air temperatures at Nicosia (Athalassa) 1991-2000 (Meteorological Service, 2017)

Sea Temperatures

In the open sea, temperatures rise to 27°C in August and rise above 22°C during the six months from June to November. During each of the three coolest months, January to March, average sea temperature drops only to about 16 or 17°C.

Near all coastal areas, three or four metres deep inside the water, temperatures are similar to those of the open sea and lie within the range 15 to 17°C in February and 23 to 28°C in August.

There are no significant daily changes of seawater temperature except on the coast in the very shallow waters, of depths less than one meter (Meteorological Services, 1993).

Soil Temperatures

Seasonal change in mean soil temperatures range approximately from 10°C in January to 33°C in July at 10 centimetres depth, and from 14 to 18°C at one metre. On the mountain ranges, at 1,000 metres above sea level, these mean seasonal values are lowered by about 5°C.

Absorption of large amounts of solar energy during the day and high radiation losses in clear skies at night causes a wide daily range of soil temperatures in summer. On the soil surface the daily variation on a typical July day in the lowlands is between 15°C near dawn to near 60°C during mid afternoon. At only 5 centimetres deep, the variation is reduced to between 24 and 42°C and at 50 centimetres depth there is no daily temperature change (Meteorological Services, 1993).

Relative Humidity

Elevation above mean sea level and distance from the coast also have considerable effects on the relative humidity, which to a large extent are a reflection of temperate differences. Humidity may be described as average or high at 65 to 95% during winter days. Near midday, in summer, humidity is very low with values on the central plain usually a little over 30% and occasionally as low as 15% (Meteorological Services, 1993).

Fog is infrequent and usually confined to the early mornings but there are longer periods of fog in the mountains during the winter when clouds often envelop the highest peaks. Visibility is generally good or excellent but on a few days each spring the atmosphere becomes hazy when dust is blown in from the Arabian and African Deserts (Meteorological Services, 1993).

Winds

Over the eastern Mediterranean's general surface winds are mostly westerly or south-westerly in the winter and north-westerly or northerly in the summer. Over the island in its entirety however, winds are quite variable in direction with the hypsometry of the land and local heating effects a significant role in determining local wind direction and speed. Differences of temperature between sea and land are built up daily during predominant periods of clear skies and cause considerable sea and land breezes throughout the summer. Whilst these are mostly pinpointed near the coasts, they regularly penetrate far inland during the summer, reaching the capital city, Nicosia, and often bringing a welcomed temperature drop as well as an increase in humidity (Meteorological Services, 1986).

Gales are infrequent over Cyprus but may occur especially on exposed coasts with winter depressions. Small whirlwinds are common in summer and appear mostly near midday as "dust devils" on the hot dry central plain. Vortices, approaching a diameter of 100 meters or so, with the characteristics of water spouts at sea and of small tornadoes on land, very rarely occur in a thunderous weather. Localised damage caused by these

vortices haves been reported on a few occasions but in general Cyprus suffers relatively little wind damage (Meteorological Services, 1993).

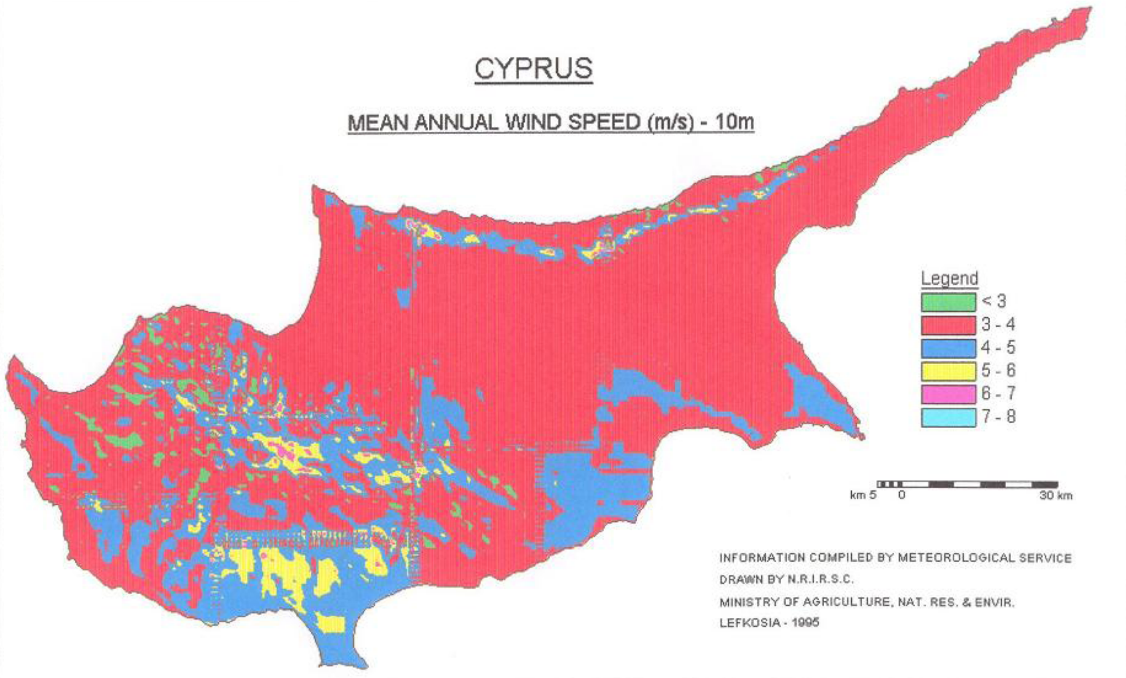


Figure 1.5 Mean annual wind speed (m/s) -10m (Meteorological Service, 2017)

Sunshine

All parts of Cyprus enjoy quite a sunny climate. In the central plain and eastern lowlands the average number of hours of bright sunshine for the whole year is 75% of the time, when the sun is above the horizon. Over the whole six months of summer, there is an average of 11.5 hours of bright sunshine per day whilst in winter it is reduced to only 5.5 hours during the cloudiest months, December and January. Even on the high mountains the cloudiest winter months have an average of nearly 4 hours bright sunshine per day and in June and July the figure reaches 11 hours (Meteorological Services, 1990).

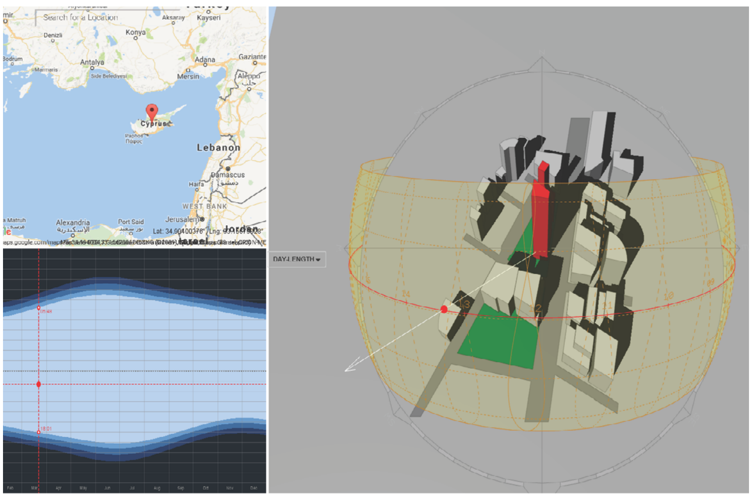


Figure 1.7 3D Sun Path Diagram (35oN latitude) (Marsh, 2017)

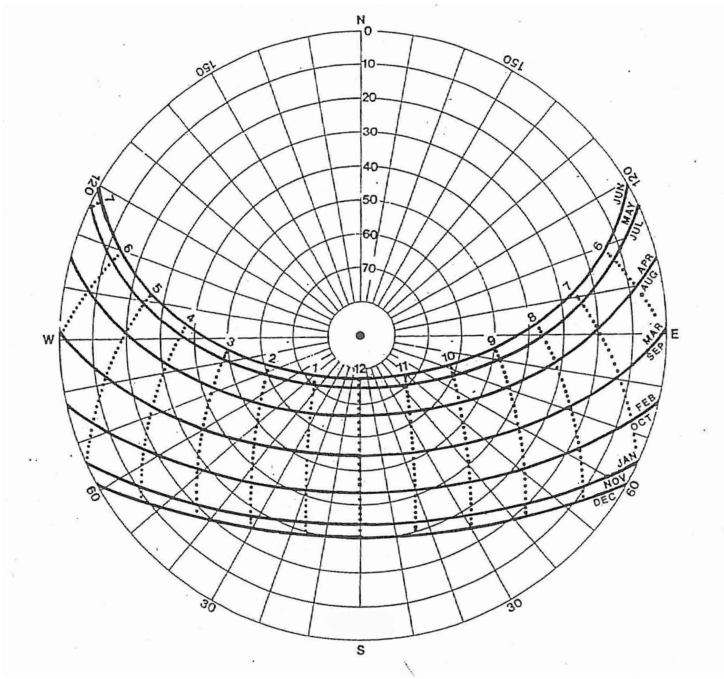


Figure 1.6 Sun Path Diagram (35oN latitude) (Watson, 1993). The sun path diagram for the given latitude can be used to determine the sun's position for any hour of the year.

Solar Radiation

The monthly mean total solar radiation on a horizontal surface on clear days at representative locations of the central plain, coastal and mountain areas varies from about 3.48 kWh/m²day in midwinter to 8.82 kWh/m²day in midsummer (Meteorological Services, 1993). The mean daily solar radiation on a horizontal surface varies from 3.32 kWh/m²day in December to 8.12 kWh/m²day in July in low land areas, and from 2.20 kWh/m²day to 7.77 kWh/m²day in the respective months on the high mountains. The direct solar radiation at normal incidences at noon varies from 0.85 kW/m² in winter to 0.91 kW/m² in summer. Thus it is seen that Cyprus enjoys a very sunny climate. The long periods of bright sunshine and the high amount of insulation, even on the high mountains, are very important factors in making solar energy a variable option.

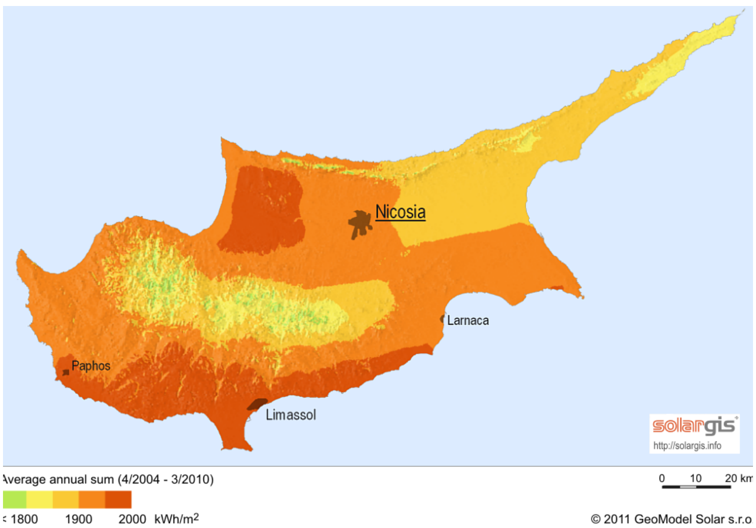


Figure 1.8 Global solar radiation (solaris, 2017)

Comfort Zones in Cyprus

The principal climatic elements, with regard to human comfort and building design, are solar radiation, temperature, humidity, wind, precipitation and other such specific characteristics. Using the psychometric chart, Olgyay's (Olgyay, 1963) bioclimatic chart, Humphreys' comfort chart and Szokolays (Szokolay, 1985) equation, specifically adapted for Nicosia, an average comfort zone was derived and applicable in Cyprus. The following conclusions were made concerning thermal comfort in Cyprus: (Lapithis, 2003)

- Thermal comfort zones depend on regional climate
- An average of 19.5°C – 29°C is the proposed temperature, within comfort zone limits
- An average of 20-75% is the proposed relative humidity, within the comfort zone limits
- The best thermal comfort is achieved during the months of April, May, October and November. These months needed no extra heating or cooling
- The results (Lapithis, 2003) showed that in order to achieve thermal comfort conditions, ventilation is required during the summer months (June, July, August and September). In this case, natural ventilation actually occurs, or if there are no breezes, then ceiling fans are needed
- In the months of December, January, February and March passive solar gains are used to achieve thermal comfort
- It must be noted that steps should be taken to avoid over heating during the summer
- The same is to be said for passive cooling needs in the summer
- The results show that all heating requirements are covered through solar energy, while natural ventilation or ceiling fans cover all the cooling needs

The research also concluded that it is impossible to accurately specify final temperatures and relative humidity for the average person, because of the following factors:

- Psychological: It is impossible to define a person's psychology within the house indefinitely. For example, although one may be a little cold, a good view of the sun, and a sense of well-being may easily stray the specific individual from seeking heat.
- Physiological: It is impossible to define a person's body mass, temperature or the amount of clothing one may be wearing.
- Practical: Passive solar design requires simple passive habits, which cannot be monitored mechanically. It is impossible for example, to be 100% sure that windows will be opened and closed, substantially enough, in order to preserve the required indoor temperature.

Learning through History

This research investigates the influence of the application of passive solar systems in traditional and contemporary architectural forms in Cyprus. It focuses on a typical Cypriot family house, and aims towards the development of a specific regional architecture, which is sensitive to both energy use and climatic conditions.

Without advanced technical knowledge, many ancient societies in Cyprus developed urban and architectural forms based on an empirical knowledge of the principles of passive thermal control. Ancient Cypriot buildings were designed with an intimate knowledge of the site and climate, in order to achieve these ancient ideals, without today's existing dependence on mechanical control of the indoor environment.

Much contemporary architectural design, however, has lost most of this intimate knowledge. Orientation, design and construction now depend on the economic use of the site or construction. Buildings are considered in terms of cost and profit. Traditional knowledge of planning has been replaced by space standards and guidelines. The harmony between the building, the site and the communities' lifestyles has been lost.

The improvement of the thermal performance of buildings using passive design techniques is a matter which has always received the attention of architects. Since the oil crisis of 1973 however, this concern has grown to form what was then called solar and bioclimatic architecture and is now referred to as green or sustainable. Recently, the development of energy calculation techniques using computers has made the simulation of the thermal performance of buildings relatively easy. The investigation in detail of the complex relationship between the external and internal environment as well as the effect of the building envelope on this relationship can now be easily studied.

Although preceding important presences in Cyprus' architectural culture, the foundations of modern Cypriot architecture were laid by a generation of architects who completed their studies in architecture abroad as the island did not allocate a local university. As the level of education grew, the field of architecture began to expand and architects were taught to embrace new attitudes and ways of thinking.

Traces of architecture on the island can be found as far back as the Neolithic period. Cyprus however, is not known for its long periods of peace and stability due to its geopolitical position. It is hence only natural that the growth and consolidation of local architecture is internationally influenced.

Approximately since 9000 BC and up until the mid 20th century AD, construction methods have varied only slightly (Lapithis, 2003) (Lapithis, 2004) (Lapithis, 2005). The construction of buildings was made economical through the use of materials found on location such as stone, wood, reeds, earth and terracotta. Structural solutions were simple and effective. For example, the length of trees available and used as roof rafters determined the dimensions of room widths.

The architectural design of contemporary buildings (Lapithis, 2004) (Lapithis, 2005) in Cyprus (post 1970) is mostly based on the educational experience of local architects. As

most Cypriot architects were educated all over the world, their designs are profoundly influenced by western architecture and have an evident tendency to recreate an international architectural style without considering the advantages of traditional architecture, the distinctive climatic conditions and social life is prevalent. Despite the fact that there are some fine examples of contemporary buildings based on correct design principles and a better understanding of the local climatic conditions, the great majority of contemporary buildings are erected without consideration of climatic conditions as well as their influence on the comfort and well-being of occupants. This is mainly due to the lack of knowledge about the thermal performance of contemporary constructional materials and methods, and consequently the shortage of building regulations.

Before Cypriot independence in 1960, specialised building tradesmen constructed dwellings. In particular, the existence of an itinerant building team was crucial because as they moved from place to place, they learned a lot from local architecture and influenced the methods of construction and building types in other regions. Local people began to travel abroad and influenced construction by bringing prototypes from other countries.

Thermal performance of traditional, contemporary and solar houses have been researched in relation to climate and in terms of the various aspects necessary for understanding such performances (Lapithis, 2003) (Lapithis, 2004) (Lapithis, 2005). Taking into account the general characteristics of dry climate and the requirements it imposes on a home's design as well as the thermal performance of traditional and contemporary houses, it may be concluded that Cypriot traditional houses have proved to be superiorly energy-efficient when compared to contemporary houses.

Building Legislations

Cyprus is a presidential parliamentary democracy and administratively is separated into Districts (6 altogether) that are managed by the District Officers appointed by the Government. In addition, there are two types of local authorities, the Municipalities (33) and the Communities (352), which are governed by separate laws. Municipalities form the core of the local government structure in urban areas and in tourist centres, whereas Communities constitute the local government structure, in rural areas. Communities with a population of over 5.000 inhabitants or smaller Communities with sufficient economic resources to function properly and independently have the opportunity to become Municipalities. The Mayors and the Municipal Council of the Municipalities, as well as the Presidents and the Community Councils of the Communities, are elected directly by the citizens for a five-year term. The Municipalities and the Communities have their own budget. They are responsible for the construction, maintenance of streets, provision of local services and the appearance of public areas, the protection of public health etc. The main sources of their revenues are state subsidies, taxes and fees.

The planning system is highly centralised. The Minister of Interior is the Planning Authority and is responsible for the preparation and publication of Development Plans. As such there are the "'Local Plans" and the detailed "'Area Schemes" for urban areas and

the "'Policy Statement for the Countryside" for rural areas. The General Development Plans contain a set of land uses including public facilities and zoning maps as well as policies, provisions and regulations to guide the development. The major advisor to the Minister is the Town Planning Board. The Department of Town Planning and Housing provides technical assistance and expertise.

The Town and Country Planning Law has been enacted, as a whole, on the 1st of December 1990. The responsibility of issuing Planning Permits rests with ten distinct Planning Authorities, which are the Director of Town Planning and Housing Department, all five Divisional Town Planning Officers in the districts, as well as the four main Municipal Councils of the island. In cases of urban complexes made up of several Municipalities and Community Councils, a new proposal of establishing a joint Planning Authority for the whole conurbation area (covered by each Local Plan) is currently under consideration by the Ministry of Interior. Building Permits can be issued by the 24 Municipalities (since 9 out of the 33 are under occupation) for the Municipal Areas and the five District Officers, for the rural areas.

The Law, considering the kind of development, specifies the appropriate drawings and any other documents, certificates etc... which have to be submitted with application form to the Planning Authority. Three main issues can be mentioned here:

1. There is not any legal obligation to submit designs or calculations for thermal, acoustic, light and fire performance of a conventional building within the application form.

2. Although civil engineering calculations have to be submitted at the building permit application process, these drawings are roughly checked and the responsibility for any structural failure remains on the civil engineer's side.

3. According to a recent regulation of 2000 all new constructions, renovations and generally any structure, have to be inspected by authorised engineers. Therefore, inspections are compulsory for freelance practitioners, though are not compulsory for Responsible Authorities. For this very reason, the enforcement of the Planning and Building laws is not so effective.

All building modifications require a "'building permit" and moreover, the modifications that are regarded as "'substantial" require an additional "'planning permit" in advance. The specific provision is unclear and therefore depends on the discretion of the respective Town Planning Authorities, to judge whether a modification is substantial or not. The painting of a building for example does not require any permit, simply because it is not regarded as a substantial modification. Therefore designers are not obliged to ask for approval of any drawing concerning painting.

There is no specific data concerning maintenance, renovations, modifications, etc. of building envelopes. Indicative data however suggest that the average Cyprus family does not pay a lot of attention to these matters, that people can extent the period estimated to finish the various works as long as possible and that they must proceed to the necessary works only when the performance of their building is intolerable, or dangerous, always looking for the absolute minimum expense. In the vast majority of cases,

improvements are related only to the painting of buildings.

No specific legislation was ever passed before the 80's concerning incentives for organised housing complexes. The only regulatory tools were the commonly used town planning restriction which concerned plot ratio, plot coverage, maximum height, maximum number of stories, a general aesthetic framework and some indirect density standards concerning the minimum surface in relation to the size of housing units. This is actually the very reason why multi-story family buildings were very few till the 80's. Some sort of incentives for organised housing complexes, up to three stories, were introduced in the revised statutory local plans in 2003.

There are no specific regulations concerning architectural and functional aspects. The authority that is responsible for issuing the Planning Permit decides whether a certain development rests within the environment of the surrounding area. There are however indirect density standards, concerning the minimum size of housing units. Practice however is much different especially as far as the aesthetic control is concerned. Problems also arise when dealing with the incorporation of small but vital structures, like solar panels, antennas etc.

Demographic and Housing Data

The Statistical Services of Cyprus provides basic demographic data approximately every 10 years. The last two census of population were carried out in 1992 and 2001 (Statistical Services, 2001):

- The total number of persons enumerated in 2001, in the area controlled by the Cyprus Government, was 689.565.
- The total number of units was 286,000 in 2000.
- Almost 85,000 of these units were built in the period from 1960-1980.
- Out of the total number of units, nearly 60,000 are apartment blocks and 125,000 are detached or semi-detached houses.
- Number of new dwellings completed in 2000 are 5,000
- Average dwelling area 189m^2
- Average construction cost was 568 Euros per m^2 .
- From the above data it can be derived that the average number of persons per dwelling, was 3,23 for 1992 and 3,06 for 2001.
- In addition to that the number of square meters per person, was 49,5 for 1992 and 61 for 2001.
- The average construction period required for completion of a project was about 1.5

years (Ministry of Commerce and Industry, 1994). Only for 22% of all projects, the period required for completion extended from 2 to 4 years. Nearly 61% of residential buildings are reported to have completed within a period of 18 months.

- Most of the new dwellings were found in Nicosia (29.3%), followed by Limassol (26.1%), Larnaca (17.5%), Paphos (15.6%) and Ammochostos (11.5%). Two thirds of the new dwellings were constructed in urban areas, reflecting a high level of urbanisation.

- In 1994, 8,079 dwellings were completed in the private sector, with an average flooring space of 170 m² and 5.4 rooms per dwelling. Of these dwellings 56% were constructed with central heating installation and 95% with a solar water heater.

- From the new houses completed in the private sector, 64.3% were single houses, 21.5% were semi-detached, and 14.2% upper-floor houses. The average number of bedrooms per house was 3.0. Living floor space was 131.1m² whereas useful floor space constituted 178.1 m² out of an average total housing area of 206.5 m².

- Out of the 8.079 dwellings completed in the private sector, 2.294 or 28.4% were reported for holiday purposes or as a second homes use. The distribution with these categories is 1,384 holiday apartments, 476 holiday houses and 434 secondary homes. As expected, the vast majority of dwellings intended for holiday purposes are located mainly in the coastal districts, Ammochostos 29.4%, Limassol 25.2%, Paphos 24.8% and Larnaca 15.0%. Nicosia accounted for only 5.6%, mainly secondary homes.

Energy Consumption

With the exception of solar energy, Cyprus has no other energy resources of its own and has to rely heavily on fossil fuel imports. The energy consumption is predominantly oil based. The only other form of commercial energy used is coal. Coal is used occasionally for cement production, when its price is more competitive to that of heavy fuel oils. More than 94% of the total primary energy consumed in Cyprus is currently imported from other, energy-producing countries. This creates not only a profound ecological imbalance but also presents a serious impact on state funds. With the exception of solar energy (Greenpeace Mediterranean, 1999), Cyprus has no other energy resource of its own and has to rely heavily on the import of fossil fuel.

The contribution of solar energy to meet the primary energy needs of the country is estimated to be 5.9% (Synergy, 1995). Thus, more than 94% of the total primary energy is supplied by imports.

The cost of imported energy for the year 1992 amounted to 145.7 millions CY pounds, representing 63% of the domestic exports. Due to the developmental nature of the economy of Cyprus, energy consumption is increasing rapidly. The per capita annual energy consumption in Cyprus is 2.28 toe, which is well above the world average of 1.59 toe/capita and below that of the European Community.

The low population, the almost exclusive reliance on oil for the energy needs, the relatively high cost of electricity, the reasonably high level of technology and the popular acceptance of solar and wind energy (even without any incentives), make the renewable energy options, particularly solar energy, extremely viable from a technical, social and economic standpoint.

The total annual energy consumption of residential buildings in Cyprus is 15.1% of the annual consumption of energy (Ministry of Commerce and Industry and the Department of Statistics and Research, 1994), while in Europe it is 9-15% (Burton et al. 1990).

According to Carvalho *et al*. (1991) comparing Cyprus to the European Community and regarding the economic activity and energy consumption, it is assessed that there is great potential for energy conservation and improvement of efficiency in Cyprus.

Total annual energy consumption refers to all energy sources those being, electricity and fossil fuels. The industrial sector consumes less electricity and yet its total energy consumption is greater than any other sector. For 1000kWh to be produced, 0.344 toe is required.

It may be remarked that the generation of electricity accounts for 36% of the total energy requirements of the country and that the efficiency of production of electricity from oil corresponding to 0.344 toe/1000kWh is low, compared to the international values typified by 0.22 to 0.23 toe/1000 kWh.

The contribution of domestic resources, and in particular solar energy, to meeting the primary needs of the country was estimated at 5.9%. Thus more than 94% of the total primary energy consumption was dominated by imports of crude oil and oil products. The total annual (1993) energy consumption (electricity included by the domestic sector) in Cyprus comprises of 15.1% with electricity at 34%. Based on consumption by households, a rate of growth of 4.6% is indicated between 1992 and 1993. In terms of end-use of energy in households, water heating holds the highest place being half of the total consumption, and more than half of the electricity.

Data was collected for carbon dioxide emissions per capita from 1990 (6.8 metric tons) through 2004 (8.2 metric tons) showing an increase of 1.4 metric tones. Cyprus is 47 on the rank as ranked by their metric tons of carbon dioxide emissions per capita in 2004.

Renewable Energy Sources

The need for renewable energy sources is one of Cyprus' greatest concerns. Renewable energy technologies harness energy sources such as sunlight, wind, water, and plant material. Unlike fossil fuels, these sources are self-replenishing and most often inexhaustible. Concern about the environmental impact of renewable energy is small in comparison to those of non-renewable energy. The adverse effects that do exist usually can be lessened or eliminated through proper planning. However, as the use of renewable energy technologies continues to grow, environmental impact will need to be addressed. Some of these impacts are outlined below.

No energy technology is free of environmental concerns. Most renewable energy technologies produce very little air and water pollution relative to fossil fuels and nuclear power. The areas of greatest environmental concern are the impacts caused by the construction and operation of renewable energy power plants. These concerns are largely addressed through proper siting of facilities, and by taking measures to ensure that any environmental impact is controlled, reduced, or eliminated. In addition to these generic environmental concerns, there are specific concerns for each type of renewable energy technology.

Cyprus has ratified different agreements such as the Kyoto Protocol in 1999, the United Nations Framework convention on climate change (UNFCCC) in 1997 and the Vienna Convention in 1992. The Memorandum of Understanding on the implementation of the EEA Financial Mechanism 2004-2009 between the Republic of Iceland, the Principality of Liechtenstein, the Kingdom of Norway and the Republic of Cyprus was signed on 16 September 2005. The Memorandum of Understanding on the implementation of the Norwegian Financial Mechanism 2004-2009 between the Kingdom of Norway and the Republic of Cyprus was signed on 19 May 2005. Under both Financial Mechanisms projects in the following priority sectors and specific fields of intervention for Cyprus will be supported such as; Integrated pollution prevention and control, reduction of CO2 emissions and management of selective solid waste and possible recycling, promote sustainable natural resources management and efficient use, sustainable forest management and implementation of management plans for Natura 2000 sites.

The Cyprus government has set amongst the main objectives of the Cyprus Energy Policy the development of Renewable Energy Sources (RES), energy conservation and harmonisation of the energy sector with the Aquis-Communataire. The national action plan for RES and energy efficiency calls for doubling of RES contribution to the country's energy balance from 4,5% to 9% by 2010 and increasing the contribution of RES in Electricity production to 6% by 2010. Within the framework of the national action plan for RES and energy efficiency, the support scheme for energy conservation and the promotion of renewable energy sources has been operational since 2004 and modified versions were in force until 2010. The Ministry of Commerce, Industry and Tourism has examined several amendments of the existing support scheme in order to be more functional and effective. The most important amendments are:

- Increase of the maximum eligible installed capacity per unit of photovoltaic that are financed from 5 kW to 20 kW and the maximum amount of grant from 16200 Euro to 65000 Euro per unit.
- Increase of the maximum amount of grant provided for the installation of small wind systems with capacity up to 30 kW from 30800 Euro to 51300 Euro per unit.
- Grant of 1200 Euro for purchasing a hybrid or fuel flexible vehicle and grant of 700 Euro for purchasing an electric or a low CO2 emission vehicle.
- Grant for energy saving investments in thermal insulation, estimated up to 21 million Euro in the next two years.

- Energy saving campaign using compact fluorescent lamps worth 4.3 million Euro until 2010, which are given free of charge to electricity consumers.

The EAC (Electricity Authority of Cyprus, 2014), as a semi-governmental organization, generated the law of 2003 for the promotion of the use of RES and energy conservation investments:

- Provided the legal framework for the preparation and implementation of schemes for the promotion of RES.
- Imposed a levy of 0.22 Euro cents/KWh on all electricity consumed. The proceeds are utilised to finance activities aimed to promote the use of RES.
- The special RES fund is managed by an independent committee (Kassinis 2007).

This legislative framework empowered the actions and the measures taken towards strategic objectives.

From the first Renewable Energy and Energy Conservation Action Plan in 1985 to the Action Plan 2002-2010 for RES in Cyprus and the implementation of energy policies for the development of RES was a long process for the Electricity Authority of Cyprus (EAC). A legislative framework has been created in order to provide the necessary background for the application of the action plan and legally support schemes for the promotion of RES. The EAC achieved today's Energy Performance of Buildings Directive (EPBD) by the process presented below:

- The first formulation of Renewable Energy and Energy Conservation Action Plan took place in 1985 and was then revised in 1998
- Operation of a first grants scheme (1998) (sectors of the manufacturing industry, hotels and agriculture)
- Following the above was the establishment of: The Applied Energy Centre (AEC) and The Cyprus Institute of Energy (CIE) (2000)
- EAC agreed to purchase electricity generated from RES
- Transmission System Operator (TSO) an independent authority (2003)
- Then procedures were specified for licensing and interconnecting wind and photo-voltaic installations to the national grid
- The formulation of an Action Plan (2002-2010) for RES in Cyprus
- Legislative framework for the promotion of RES and conservation of energy (Apr 2003)
- Cyprus Energy Regulatory Authority (CERA) (Jan 2004)

- New grant schemes (Feb 2004)
- New enhanced grant schemes for RES (Jan 2006)

All the above actions have provided a background for the implementation of the policies. The actions taken by the EAC can be separated into two levels: the legislative framework and the measures for the achievement of strategic objectives.

Biomass

Most of the biomass energy (heat and electricity) used today comes from the combustion of wood, agricultural residues, and MSW. If the biomass is produced and harvested in a sustainable fashion, then there is no net increase in carbon dioxide production, since plants consume carbon dioxide in photosynthesis. Particulate in air emissions can be controlled through efficient combustion and treatment of the combustion gases.

An alternative to direct combustion of biomass is gasification, where biomass is heated in an airtight chamber and then oxidised to produce a medium Btu content gas. This gas can be burned in a furnace, boiler, or gas turbine to produce heat and electricity. Gasification has the benefit of being more energy-efficient and less polluting than direct combustion. Gasification technologies have been developed on a small scale, and are being scaled up for electric power plant applications.

Incinerating MSW is of more environmental concern, mainly because of the non-biomass materials that are contained in MSW such as plastics, heavy metals in batteries, and chemicals in household cleaning and maintenance products. The European Union has strict regulations regarding air emissions and disposal of ash from MSW incinerators, while Cyprus has only recently established such regulations.

Methane generated in sewage treatment plants, landfills, and anaerobic digestion systems on farms is an extremely clean fuel. The combustion of methane for energy is less detrimental to the environment, as methane is considered much less hazardous as a greenhouse gas than carbon dioxide.

Agricultural crops, trees, and even waste paper can be converted to alcohol fuels for transportation. Corn, sugar cane, and other high sugar content crops are used to produce ethanol. Biodiesel is produced from soy-beans and rapeseed. The conversion of these biomass materials to liquid biofuels poses few environmental hazards. The combustion of these fuels creates less overall air pollution than gasoline and petroleum diesel.

Geothermal Power plants

Vast amounts of energy can be obtained by tapping the heat trapped in rocks, water, and steam beneath the earth's surface. Air pollutants from geothermal power facilities include hydrogen sulphide, benzene, radon, ammonia, and boron. Liquid effluents may

contain toxic elements such as mercury and arsenic. There is speculation that some geothermal power plant operations, such as injection of fluids into the ground, may cause seismic activity. On the other hand, removal of large quantities of water from the ground can cause the land to sink or subside. The geothermal industry uses filters and scrubbers to control air and liquid pollutants, as well as mufflers to reduce noise. In Cyprus, geothermal power plants do not exist, mainly because the geographical potential does not exist. The areas of environmental concern associated with geothermal energy are air pollutants, solid wastes, brine disposal, noise, seismic disturbance, and land subsidence. The type and extent of these impacts is highly site specific, as they depend on the nature of the geothermal resource.

Wind Energy

Wind is an abundant source of clean mechanical and electrical energy. Some of the environmental concerns of using wind energy on a large scale are the land requirements, noise, and visual pollution. Careful wind machine design and siting, however, can reduce these impacts. Wind farms can be used for other purposes, such as agriculture and ranching.

Wind studies have been conducted for Cyprus, both indicating that mean wind speeds are enough for introducing wind energy and the goal to achieve 10% wind power is possible (European Wind Energy Association, 1998) (Pashardes et al. 1995) (Metsovio Polytechnic at al. 1998). It is essential to establish a firm target towards wind power as an energy source, where there is potential for exploiting wind as an energy source.

Solar Thermal Energy

Solar thermal systems typically concentrate sunlight to generate heat. This heat may be used directly for water and space heating, industrial processes, or to produce steam for operating electricity-production turbines. Examples of solar thermal systems range from the solar hot water heaters on the top of thousands of homes in Cyprus to the solar thermal-electric ‘power tower’ in Barstow, California (Caddet, 1994). While operating, solar thermal systems produce no air pollution or solid wastes. The most significant environmental impacts associated with solar thermal technologies are the great land area requirements and visual impacts of utility-scale systems. Some solar thermal systems use antifreeze solutions or other fluids for heat transfer. These fluids are generally non-toxic, but must be handled and disposed of correctly.

Cyprus has excellent conditions for grid connected solar thermal power generation. Appropriate site locations for solar thermal electricity are normally in arid to semi-arid countries situated in the sun-belt, which includes the Mediterranean region, and naturally Cyprus. Considering the similarities between Crete and Cyprus, there is no reason why the suggested THESEUS power plant could not be implemented in Cyprus. A 100MW plant could generate close to 10% of today’s consumed electricity in Cyprus. (Greenpeace, 1999)

Photovoltaic Systems

Solar electric or photovoltaic (PV) technology has advanced significantly and could become a major source of energy throughout Cyprus. PV systems use solar cells to convert sunlight directly into electricity. PV cells have no moving parts, are easy to install, require little maintenance, contain no fluids, consume no fuels, produce no pollution, and have a long life span. PV systems pose little harm to the environment, and have brought electricity to remote areas where power lines do not reach. In Cyprus, most homes are already grid connected. This means that the electricity is supplied via national grid. By utilising the national grid, expense of the batteries can be avoided. The whole national grid can be used as a giant battery. The Experimental Solar House is one of the first grid connected house, with others following.

Active Systems

A large portion of a building's annual domestic hot water (DHW) needs can be supplied by a relatively inexpensive active hydronic system using about $9m^2$ of collectors for a typical residence. A heat exchanger, usually in the hot-water tank, keeps the working fluid separate from the potable water supply. Such a system, however requires a backup energy source, but may pay for itself in energy savings.

High-temperature solar collector panels may be used to power an Absorption-Chiller Air Conditioning. Such systems are relatively expensive but may be cost-effective in climates where plentiful sunshine and a substantial need for air conditioning exist. Also, Heat Pumps may be used in conjunction with solar panels. Solar heat boosts the heat pumps source during the winter, and during the summer the heat pump can discharge heat to the outdoors at night through the collectors.

The Cyprus government has helped the promotion of active solar energy by the following actions:

- Making solar water heating mandatory in refugee housing.
- Providing loans to individual and hoteliers for installation of solar water heaters.
- Technical support: consisting of testing of collectors, advice to industry for improvement of products and to consumers for efficient utilisation.
- Making the materials used for the construction of solar water heaters duty free.

All these measures have helped the promotion of solar energy. The technical support has been of increasing importance, becoming practically critical now that further expansion of market depends on quality and product diversification. It is about time to act the same way for passive solar energy. The domestic hot water market for individual houses is closing upon saturation. However, replacement of old units and installations in new houses do represent a significant share of the market. Hot water systems for apartment buildings and hotels will probably constitute the largest share of the market in the near

future. However, efficient collectors and careful system design are essential for the exploitation of this market. Air collectors with multiple uses (e.g. drying of agricultural products, heating of water, heating of green houses, house heating) represent another large share of the future market.

Passive Solar

The energy required for heating and cooling of buildings is approximately 6,7% of the total world energy consumption. By proper environmental design, at least 2,35% of the world energy output can be saved (Agrawal, 1988). Within Cyprus, in the coastal and central areas, energy needs for cooling can amount to two or three times those for heating, on an annual basis (Goulding. 1993). Utilisation of the basic principles of heat transfer, coupled with the local climate, and exploitation of the physical properties of construction materials, could make the control of the comfort conditions in the interior of buildings possible. Even in areas with average maximum ambient temperature around 31.7°C, comfortable conditions inside buildings can be achieved by means of proper building design (Shaviv, 1984) that frequently makes the use of air-conditioning units in dwellings unjustified. It is estimated (Commission of the European Communities, 1990) that an increase of 9mtoe (million tons of oil equivalent) per annum in the total technical potential solar contribution (all potential solar usage is exploited) is possible in all EU countries by the year 2010, compared to 1990, if passive cooling is applied in dwellings.

Passive cooling strategies in the design of buildings in Cyprus should be considered, since the extensive use of air-conditioning units is associated with the following problems:

- Wide use of air-conditioning units has caused a shift in electrical energy consumption in the summer season and an increased peak electricity demand (Argiriou et al., 1993). Peak electric loads impose an additional strain on national grids, which can only be covered by development of extra new power plants.

- Increased electrical energy production contributes to exploitation of the finite fossil fuels, to atmospheric pollution and to climatological changes (Akbari et al., 1988) (Brow, 1988).

- Heat rejection during the production process (for electrical energy and air-conditioning units) and from the operation of air-conditioning units themselves, increases the phenomenon of the 'urban heat island' (Akbari et al., 1988) (the climate modification due to urban development, which produces generally warmer air in cities than the surrounding countryside).

- Ozone-layer depletion can be caused by CFCs and HFCs (the most common refrigerants of currently used air-conditioning units) from possible leakage during manufacture, system maintenance or unit failure (DOE, 1992).

- Increase indices of illness symptoms (lethargy, headache, blocked or runny nose, dry or sore eyes, dry throat and sometimes dry skin and asthma), known as 'sick building

syndrome' (Burge, 1991) is reported in people working in air–conditioned buildings.

- Occupants' dissatisfaction with indoors comfort conditions.
- Economic and political dependence of Cyprus with limited natural resources on other countries, richer in natural resources.
- Installation of air-conditioning units presents an extra cost in the construction of a building, followed by an additional operation and maintenance cost (King, 1993).
- Expenses for importation of A/C units: countries with hot climates exhibit an increased rate of sales of air-conditioning units. In Cyprus, sales of packaged air conditioning have increased by 900% over recent years (Santamouris, 1990), with 80% of them delivered to the residential sector (King, 1993).

A few Cypriot architects are now designing new houses and retrofitting older houses to passively use the sun and other environmental factors to reduce energy costs. Passive solar systems are characterised by having few or no moving parts. Typically, the south side of the buildings have extensive areas of insulating glass (or even a greenhouse), the east and west sides have less glass; and the north side, which receives no sun and is exposed to winter winds has little or no glass. The orientation is of course reversed in the Southern Hemisphere. Roof overhangs jut out over the south-facing glass, in order to admit sunlight to the building in the winter, when the sun is low in the sky and heating loads are high, and to keep sunlight out of the building's interior in the summer, when the sun's path is higher. Effective insulation is considered an essential element of passive design.

Energy Performance Building Directive

The energy performance of the building means the quantity of energy that a building consumes or an estimation of consumption required for the different needs of the building. This could include heating, water heating, cooling, ventilation, and lighting. This is estimated with different values in conjunction with the thermal insulation, the technical specifications and the specifications of the electrical and mechanical fittings, the design and the placement of the building in coordination with the climate, the building's exposure to the sun and the influence of neighbouring buildings, the energy production from the same building and other factors that influence the energy demand.

Regulations for the energy performance of buildings have been adopted in compliance with the EPBD directive 2002/91/EC. (Cyprus Institute of Energy, 2012). Minimum energy efficiency requirements for new buildings have been set. The Cyprus reference residential building includes all the minimum technical characteristics such as the building shell thermal code, energy efficiency of HVAC equipments, mandatory installation of solar thermal system for hot water, provisions for the installation of a photovoltaic system. A national calculation method named SBEMCY, based on a reference building, has been developed and is applied to prove and get a building permit for a new building that passes the minimum requirements (B class building) and also for the issuance of an en-

ergy performance certificate.

New legislative regulations for the mandatory inspection of boilers and air conditioning systems have been enacted but until the end of 2009 they had not been implemented. Due to the hot climate conditions, the use of split air conditioning units is standard in Cyprus and therefore air conditioning constitutes a significant part of electricity consumption and maximum power demand during peak seasons.

A financial support scheme has been in place providing grants for existing dwellings in energy efficiency improvements including thermal insulation, double glazing, solar thermal water heaters and geothermal heat pumps.

For Cyprus the methodology that was prepared concerns:

- Buildings that are used as residences.
- Buildings that are not used as residences of smaller area (1000m^2) which do not have a central system of air treatment.
- The methodology is in place to calculate the energy needs of a building in heating, refrigeration and production of hot water for use.
- Comparison of individual energy needs of real buildings with the building of report.
- Includes parameters as efficiency of instruments, contribution RES etc.
- The final result will lead to the certification of building.

The categories of buildings that are excluded from the obligation of observation of minimal requirements of energy output and for publication of certificate of energy attribution of building are the following:

- Buildings and memorials that are officially protected because of particular architectural or historical value.
- Buildings that are used exclusively as spaces of religious adoration.
- Temporary buildings with a duration of use of maximum two years.
- The section of an industrial installation where the production is carried out.
- Rural or non lived in buildings which have low energy requirements.
- Isolated buildings with a total useful area of under 50m^2.
- The present regulations are implemented in all cases of construction of new buildings as well as in cases of buildings of total useful surface above 1000m^2 that suffer radical renovation. It is comprehended that in the cases of buildings of total useful surface above 1000m^2 that suffer radical renovation, their energy output is upgrad-

ed so that it fills the requirements of the minimal energy attribution of a building, at the level of the judgement of the appropriate authorities; that is technical, functional and economical feasible.

Energy performance certificates:

- By the of provisions of the roads and building (Energy Performance of Buildings) regulations 2006 and article 8 of the present law, at the manufacture, the sale or the leasing of a building an energy performance certificate (EPC) has to be given either to the tenant or the new owner of the building.
- The certificate of the building energy performance includes reports in order to allow the interested parties to compare and evaluate the energy performance.
- The EPC certificate of energy attribution of building is accompanied by constitution for the improvement of the building's energy performance, taking into consideration the economic and financial means.
- The EPC is carried out by a building's specialist, whose qualifications are determined by regulations.
- The certification for apartments or units that are designed for separate use in building complexes, could be based on a common certificate for the entire building of the complex with a communal heating system, or the evaluation of a representative apartment of the same complex.
- The Law on Labelling CE that concerns requirements of minimal energy performance of certain appliances of wide use as well as the Law on the Energy Labelling of domestic appliances that has applied from April 2004 and concerns: refrigerators and freezers, washing-machines, tumble dryers of clothes, dish-washers and air conditioners.

Looking at methodologies prepared by the Commission so far, some calculations have been carried out for the energy savings caused from specific energy efficiency measures such as CFL lamps, thermal insulation, double glazing of existing buildings, solar thermal heaters, and thermal building code for new buildings.

In parallel, using criteria in the MURE database, the impact of measures can be characterised. The following measures have the most impact:

- The energy performance of building regulations, minimum efficiency requirements for new/renovated buildings. The specified thermal transmittance (U-values) for new buildings are 0.85 W/m^{2}k for walls, 0.75 W/m^{2}k for roofs, 3.8 W/m^{2}k for glazing, U mean=1.3 W/m^{2}k for houses, U=1.8 W/m^{2}k for commercial buildings. Considering that no building codes or thermal standards were applied prior to 2007 the new requirements will deliver, according to calculations, a minimum of 30% energy savings comparing to the existing building stock (specific energy consumption in kWh/m^2/year).

- The financial incentives provided for energy efficiency investments in buildings and industry. Most technologies are covered by these incentives. Particularly for existing houses, the scheme provides grants of up to 2000 Euros for the thermal insulation of walls, roofs, double glazing. Thermal insulation has a high energy conservation impact. Considering that a roof without insulation has a thermal value of U=3 and after the insulation this drops to U=0.5 W/m^2k, overall energy savings of 30% are estimated.

- National action plan for the development of public transport. Radical changes and significant investments in developing high quality, effective and environmentally friendly mobility covering all regions of the island. This is a package of high impact measures such as the purchase of 1000 new efficient buses. The target set by the government is to increase the usage of public transport from 2% in 2008 to 10% in 2015.

Environmental Education

Earth's landscape has real value; a value that is not countable in money but measured in importance. It significantly affects various areas of general interests, whether cultural, social, environmental, ecological or economic. It also provides for our food, water and a place to live. Numerous European and international movements have long fought for its protection, yet it is crucial to acknowledge that without citizens' understanding, willingness and involvement to bring forward change, little can be done. Instead of embracing nature's offerings, we have mostly been throwing these away.

Notably, using earth's resources for the construction of buildings is not a new concept but a revived one. Surprisingly, the concept of sustainable architecture has existed since antiquity. Traditionally, builders made use of elements found in the natural environment, such as the geomorphology, soils, climate change and direct solar energy, and managed to make use of these in order to create buildings without significant consumption.

Living in the 21st century is not an easy task. Mankind today is facing its greatest challenges of all; a social, economic and ecological crisis. People nowadays focus their attention to the economic and social aspects of this catastrophic wave and in some unconscionable way they ignore environmental alerts. It might not be all of them but still those who, not only don't care but are truly unaware of the seriousness of the ecological crisis hold the majority of Earth's population. What they don't understand is that scientists are no longer simply talking about climate changes or merely urging people to recycle the products they use. Recycling is one the best things one can start doing today but unfortunately, it's not enough (Filippidi, 2012).

The Environmental Education Movement which had a long history before its outburst in the 1960s was extremely crucial in this respect. Various efforts have been made through the years to get people closer to nature outside and/or throughout our education systems and many organisations were established to promote environmental awareness to the general public around the globe. The results of their efforts are amazing but unfortunately still not enough. Mankind has been trashing out the Earth's natural resources so

much that the only way to save the planet from now on, is by changing our whole system and the way we live into a more sustainable environment.

However, the long history of the EE movement has a lesson to teach: training and educating people about the environment is not enough. Humans learn by practice and the best practice of an action is to incorporate it into people's daily way of living. While we owe to EE the amazing fact that more people are environmentally active, alert and aware today than they were years ago, we also owe to it the mere existence of Sustainable Architecture ('SA'). The construction science has engaged architecture in this movement in an effort to reinforce the idea of the ecological way of living sustainably in ecological cites. It is in this sense that SA –and of course together with other relevant sciences-might hold the key to save the planet and humanity.

EE is all about educating individuals about the natural and built environment by engaging them from a very early age in an active learning process. Nowadays this has extended at all levels, from primary to higher education, and most countries around the globe have committed themselves through legally binding treaty obligations in the provision of EE (Pandley, 2006).

Twenty years ago, principles and practices of sustainable architecture were rarely included or pursued within conventional academic curricula. The most likely explanation for this phenomenon was that the practice of sustainable architecture was considered, by most academics and non-academics alike, as a fad. The transition from fad to fashion and from fashion to necessity was instigated by the energy crisis which acquired the public's attention in the 1970's, the repercussions of which have been escalating dramatically ever since (Papadopoulou et al. 2011).

Necessity or not, a large number of academic institutions teaching architecture do not embed environmental agendas into the design culture they promote. It must, of course, be noted that effective, environmentally responsible architectural design does not require striking labels such as "ecological design", "green buildings", or "sustainable architecture". In fact, the frequency of use of these terms in a casual conscience increases the risk of losing the impact of their intended meaning.

Schools nowadays focus on the creation of successful graduates in terms of academic achievement. They focus on the 'shaping' of personalities, following a uniform mission and the successful entrance to a university. This affects the definition of educational spaces and education directly. In this competitive race many aspects concerning the way of living in terms of moral principles or purpose and the complexity of contemporary human systems are set aside. Many movements and voices have taken a position on the direction of contemporary societies, especially after huge environmental problems threatened our existence (Hadjivasiliou, 2012).

It is necessary to set a framework for educators, a framework for students and future citizens. The most critical element of this framework is the understanding that the world is interconnected through its communities, both natural and human. The separation of natural and human communities is a subject of philosophical discussion; especially today where human activity has created an imbalance in natural systems, a part of which is also

humans. At the level of ecosystems there is a strict definition of the terms natural and artificial.

Sustainable design for buildings means the maximisation of positive effects of the building on a series of aspects concerning the human systems and nature and minimising its negative impacts, over the whole of its life. The design process should bring together the following elements in an integrated package: ventilation, daylight and sunlight, flexibility, educational needs, heating, domestic hot water, solar gains, existing premises (Hadjivasiliou, 2012).

A crucial argument that transpires from this book is whether environmentally responsible architecture should be regarded as a specialisation within architectural education or whether the entire spectrum of architecture should be taught as a science and as an art that is equally accountable to man and to the environment. This begs the question: Shouldn't architecture always be ecologically responsible?

Bioclimatic design practices offer simplicity, greater reliability, occasionally lower construction costs, and inevitably, lower heating and cooling maintenance fees. It is not a building add-on, but an integrated element of a building's architecture. All that is required is intelligent design.

Key principles of Sustainable Design

The key philosophy of Sustainable Design lies before one even starts designing. The architect must first be in a position to know what it is that is about to be achieved through his design. In this respect, one must first understand what type of relationship he urges to bring forward between humans and their environment, how deep the influence must be and to what aspects it must extend.

Among the main principles of Sustainable Design, the following is a list of the most important ones:

- Select and use land site efficiently
- Assess the level of environmental impacts
- Minimise the building's energy needs by using natural resources efficiently
- Create healthy buildings not only in terms of choosing non-chemical materials in the construction process but also in terms of contributing to the overall mental health and well-being of individuals. This may be achieved by providing safe and healthy environments, enough spaces for rest and recreation, take into consideration indoor air quality and temperature comfort and ensure green spaces
- Make a sustainable material selection and design to enable future building material reuse and recycling

- Build only when necessary and build small
- Make sufficient use of available resources like water, sunlight, wind and land. (Sassi, 2006)

Considering the above the aim under these circumstances is to create a building that will promote Environmental Education and a sustainable way of thinking in order for Environmental Education and Sustainable Architecture to have a real impact in people's lives. To achieve this, the building should address the following:

- Minimise negative environmental impacts associated with a building's usage but also construction
- Address people's practical needs of the current way of living and re-introduce them with a new way of living in a smart way
- The surrounding environment should enhance psychological and mental well-being in order to gain people's attraction as the materialistic human being of the 21st century tends to get attached to material objects
- Must enable human interaction within the built environment in order to promote EE through practical learning. In some countries this has been achieved by including citizens in the design and construction process in communal projects. This not only can ease the transition into a new way as well as enhance people's environmental knowledge.

THERMAL COMFORT

Introduction

The thermal environment in which humans live and carry out their day-to-day activities is predominantly influenced by the impact of climate. The instability of the thermal environment affects the quality of human life, the normal functioning of their minds, their health and in extreme conditions, causes serious psychological and physical damage or death. Acclimatising to various extreme climatic conditions is physiologically and psychologically impossible. The idea of creating a thermally satisfying artificial environment has been put into practice since early man learned how to protect himself from environmental extremes.

Socrates (Greece), and Vitruvius (Italy), analysed a few thoughts on the climatic suitability of buildings. They were the first to analyse thermal comfort for Mediterranean climate. Environmental temperatures were already being considered by the late eighteenth century (Boer et al. 1985). The development of highly effective heating systems and the appearance of new air-conditioning equipment made it quite possible to heat in the winter and cool in the summer (Boer et al. 1985).

Shelter, as a protective envelope, confronts the undesired impacts of climatic elements and also secures the privacy and safety of its occupants. Further improvement in the thermal quality of the indoor environment is achieved through mechanical means, i.e. by the instalment of a heating and/or cooling system. However, the recent growth in the mechanisation and industrialisation of Cyprus along with a wide access to energy resources has resulted in far greater expenditure on mechanical means of stabilising the thermal quality of the artificial environment to acceptable conditions. The introduction of a new way of building without taking climatic conditions into consideration, has seriously affected the energy consumption of Cyprus as well as the achievement of thermal comfort.

Heat Exchange Between the Body and the Environment

The relative amount of metabolic heat exchange between the body and the environment depends upon the degree of physical activity, the level of clothing, properties of the environment and the ambient air velocity. A body is said to be in a state of thermal equilibrium when the rate of heat storage within it is assigned a value of zero. A positive or negative value means that the body is gaining or losing heat. To maintain a thermal neutral condition some regulation of surface heat transfer is required. The steady thermal state of the human body may be expressed by the heat balance equation:

Heat Storage = Metabolic Rate ± Work rate ± Total Latent heat Loss ± Radiant Heat Transfer ± Convective Heat Transfer (W/m$^{2)}$

Monitoring body weight, which depends on several environmental factors described above, can control the total latent heat loss. Radiant and convective heat transfer depends upon the environmental mean radiant and air temperature. The surface heat transfer coefficients for radiation and convection.

Thermal Stress

Thermal stress is experienced when the thermal balance between the body and the environment is upset through inadequate conditions of heat balance where the rate of heat generation in the body is not equal to the rate of heat loss. The physiological mechanisms such as the nervous, muscular, circulating and breathing systems, operate optimally within a narrow temperature range. This temperature range is maintained by a thermo-regulatory system, which establishes a heat balance within a wide range of environmental conditions.

The deep body temperature must be maintained at about 37°C for the effective operation of its component organs. Under extreme activity or heavy work, the temperature may rise above 37°C, and the thermoregulating system might operate for short duration, but when it reaches 42 to 43°C, the system will break down and may cause death. Conversely, temperatures below 36°C may result in muscular weakness and death (hypothermia) (Bansal et al. 1974).

Due to Cyprus's climatological conditions, the loss of heat from the body becomes more difficult due to an increase in temperature caused by increase in physical activity. This may cause the body temperature to rise above 37°C. The body's vasomotor regulation against hot conditions then operates by allowing blood to flow to the skin, thereby increasing the dissipation of heat into the environment in order to bring down the body temperature to 37°C. But, in spite of the increase of blood flow to the layers of the body just under the skin and increasing the rate of circulation of the blood, cooling of the body may still be inadequate. In such circumstances water will then be released from sweat glands for evaporative cooling. When the body temperature rises more than 2°C above 37°C, people suffer major losses in efficiency, become sluggish, tired and sleepy. Continuous body temperature rises above 43°C can be lethal.

Body Heat Loss

Since body heat temperature must remain at 37°C, all surplus heat, including simultaneous heat gain from hot air and solar radiation, must be dissipated into the environment. Heat loss from the skin takes place by a complex mixture of radiation, evaporation, convection and conduction. The rate of heat loss depends on the temperature of the air, the mean temperature of the surroundings, air movement, relative humidity, activity and clothing. Body heat loss to the surrounding environment is briefly described below.

- **Heat loss by convection:** The heat transmission from the body to the air in contact with the skin or clothing is replaced with cooler air.
- **Heat loss by radiation:** This is the heat loss from the body surface to the surrounding surfaces when there is a temperature difference between the two surfaces.
- **Heat loss by evaporation:** Body heat loss by evaporation takes place when excess heat cannot be lost by convection and radiation alone.

- **Heat loss by conduction:** This is the heat loss that takes place when there is direct contact of the skin with an object of lower temperature.

Heat Balance and Heat Balance Equation

One of the most important functions of the body's thermo-regulatory system is to maintain an essential internal body temperature for healthy survival. During long exposure to a constant thermal environment with a constant metabolic rate, a heat balance will exist such that the rate of heat generation in the body must be equal to the rate of heat loss from it, and there should be no significant heat storage within the body. Based on Fanger's (Fanger, 1970) equation the above conditions can be expressed as follows:

$H-Ed-Esw-Ere-L=K=R+C$

H =Internal heat production in the body

Ed =The heat loss by water diffusion through the skin

Esw =The heat loss by evaporation of sweat from the surface of the skin

Ere =The latent respiration heat loss

L =The dry respiration heat loss

K =The heat transfer from the skin to the outer surface of the clothed body

R =The heat loss by radiation from the outer surface of the clothed body

C =The heat loss by convection from the outer surface of the clothed body

The skin senses the way in which the human body responds to environmental changes. The feeling of comfort or discomfort depends on the skin temperature. The average skin temperature should be maintained at 34°C for thermal comfort. This is accomplished by balancing the heat input to the skin and the heat loss. Either the body will gain or lose heat when there is a temperature difference between the body and the environment or evaporation will take place.

If heat balance is disturbed by internal or environmental changes, the thermo-regulatory mechanism is activated to bring it back to a balance condition through the process explained previously. However, this is only temporary and if overheating persists, sweating will take place. Conversely, in a cold environment, violent shivering may occur which increases metabolic heat production for a short period of time in order to maintain balance conditions.

Critical Body Temperatures

The limits of existence of human life can be defined in the terms of deep body temperature as 35°C and 40°C, the normal being about 37°C. The skin temperature should always

be less than these values and the temperature of the environment should be slightly less than the skin temperature in order to allow adequate, but not excessive, heat dissipation (Boer et al. 1985). The range of environmental conditions, which allows such adequate, but not excessive, heat dissipation, will allow a 'sense of physical well-being,' commonly assigned as comfortable and thus referred to as the 'comfort zone.'

Skin Temperature	Deep Body Temperature	Physiological zone
Pain: 45°C	42°C	Death
	40°C	Hyperthermia Evaporative Regulation Vasodilation
31-34°C	37°C	Comfort
	35°C	Vasoconstriction Metabolic regulation Hypothermia
Pain: 10°C	25°C	Death

Table 2.1 Critical body temperature (Szokolay, 1985)

Thermal Comfort Zone

Thermal comfort is a subjective quality, personal to the individual. It cannot be precisely defined. However, there have been many attempts by several researchers in the field to describe the condition of thermal comfort. Nevertheless, some discrepancies in the definitions do exist. In general, the majority of definitions agree that it is the condition of the mind, which expresses satisfaction with the environment (ASHRAE, 1977). It is also the state in which a person will judge the environment to be neither too cold nor too warm, a kind of neutral point defined by the absence of any feeling of discomfort (Markus et al., 1980). It can also be described as the condition of neutral state in which the body needs no adjustment to maintain its proper heat balance (O'Callaghan, 1978).

A human's intellectual, manual and perceptual performance is found to operate on high efficiency for long periods of time, when the environment is considered comfortable. Within the limits of this zone or under a range of conditions, the thermo-regulatory mechanism of the body is in a state of minimal activity. It is also a condition of a neutral state in which the body needs to take no particular action to maintain its proper heat balance. Involuntary actions such as sweating, vasoregulation and shivering of the body occur outside this neutral state.

The following works summarise some of the investigations and experiments carried out to determine the comfort zone of human beings. Markham (Markham, 1947) suggested that sunstroke or heat stroke was the upper temperature limit for man's existence with

the freezing point as the lower limit. The ideal temperature may be assumed to be midway between these two extremes. He suggested that a temperature from 15.6 to 24.5°C as constituting an ideal zone, with relative humidity varying from 40 to 70%.

Vernon and Bedford (Vernon et al..,1936) stated that the ideal temperature, with slight air movement was 19°C in summer and 16.7°C in winter. Bedford gives the ideal indoor temperature as 17.8°C in winter and defined a comfort zone that ranged from 13.2 to 23.2°C in the summer.

For different climatic regions, Brooks (Brooks, 1950) recommended that the comfort zone for Britain lies between 14.5 to 21.1°C, 20.6 to 26.7°C for the United States and between 23.4 to 29.5°C in the Tropics with relative humidity between 30 to 70%.

Houghton and Yagloglou (Houghton et al.. 1924) suggested that the comfort zone was between 17.2 to 21.7°C for both men and women and the optimum effective temperature was at 18.9°C.

Saini (Saini, 1980), who has been working extensively on projects in hot-arid climate, has made some interesting observations on the comfort range for such climate. He suggested that thermal comfort for hot-arid climate lies between 31.1 to 33.9°C.

The above range of observations outlines the probable range of comfort zones for people. However, Olgyay (Olgyay, 1967) argued that there are no precise criteria by which comfort can be evaluated. He suggested that it could be defined negatively as a situation where no feeling of discomfort occurs. This “no feeling of discomfort zone” is very similar to the zone of thermal neutrality. The comfort zone does not have real boundaries as comfort parameters are based on arbitrary assumptions. The only criterion adopted for the definition of a comfort zone are at conditions where the average person will not experience the feeling of discomfort. This has led to the emergence of the ‘lack of discomfort’ theory.

Since comfort zone is a subjective assessment of environmental conditions there is no precise criterion by which comfort can be evaluated. It can be defined negatively as a situation where no feeling of discomfort occurs, which constitutes the perimeter of the comfort zone that is the ‘lack of discomfort’ zone.

Work on discomfort by Billington (Billington, 1967) indicated that the following elements result with a fall in productivity, health and an increase in industrial accidents:

- Conditions of stress
- Increase in air temperature
- Varying humidity and rate of air flow
- Increase in effective temperature

It was suggested that provided a person can be suitably clothed, thermal balance is possible for a wide variety of temperatures. The mean temperature of a room may be chosen upon criteria other than the sensation of warmth, but optimum performance of a particular task or the ability to be lightly dressed yet sufficiently warm. While working on the same subject O'Sullivan (O'Sullivan, 1973) stated that there is in fact no such thing as a comfort zone but rather that there are zones of discomfort, lack of discomfort and pleasure. Webb, Humphreys and Nicol tend to support these views.

The concept of a lack of discomfort zone suggests that thermal balance is possible for a wide variety of temperatures provided a person can be suitably clothed. Design for a lack of discomfort zone must recognise that differences are to be foreseen from individual to individual, under similar conditions. An individual human being prefers to have a degree of control in his environment and people do not stay uncomfortable if they can help it. They either change their environment or adapt to it by changing activity, posture, clothing or physiology. The behavioural response of an individual to any particular stimulus depends upon social conditions and constraints. Imposing of controlled comfortable constant thermal conditions may not be acceptable physiologically or socially. Allowance for flexibility can lead to a greater satisfaction.

It is important to consider that the design of an internal environment largely depends on the primary elements of the building itself, particularly the climatic modification characteristic of the building fabric. Lack of consideration of the above may lead to the unsatisfactory thermal performance of a building and may affect the internal comfort of a building itself.

The most widely used comfort index is that developed by Fanger (Fanger, 1970). Thermal comfort is defined as the condition of mind, which expresses satisfaction with its surrounding thermal environment. Dissatisfaction may be caused by warm or cool discomfort of the body in general, as expressed by the PMV (Predicted Mean Vote) and PPD (Predicted Percentage of Dissatisfied) indices (Fanger, 1982). Due to individual differences, it is impossible to specify a thermal environment that will satisfy everybody. A percentage of occupants can always be expected to be dissatisfied. Nevertheless, it may be possible to specify environments predicted to be experienced as acceptable by a certain percentage of occupants. In the ISO standard, comfort requirements are specified to be satisfactory for at least 80 percent of occupants.

In steady-state conditions, ones' thermal sensation is mainly related to the thermal balance of his/her body as a whole. This balance is influenced by his/her physical activity and clothing, as well as by environmental parameters such as air temperature, mean radiant temperature, air velocity and air humidity. When these factors are known, the thermal sensation of the body as a whole can be predicted by the PMV index (Predicted Mean Vote), utilising a seven-point scale from cold to hot (Fanger, 1982). The PMV may be calculated by computer formula and tables or may be measured directly by an instrument (Madsen, 1976). The ISO (International Organization of Standardization) standard recommends the following criteria for the Predicted Mean Vote:

$0.5 < PMV < +0.5$

This means a PPD (Predicted Percentage of Dissatisfied) of lower than 10 per cent. Corresponding comfort limits for the temperature may be found from figure 2.2 as a function of activity and clothing. The temperature given in figure 2.3 is the operative temperature that is uniform of an enclosure in which an occupant would exchange the same amount of heat by radiation plus convection as in the actual non-uniform environment. For most applications, the operative temperature is approximately equal to the mean value of mean radiant and air temperatures. The curves show the optimal operative temperature, in other words, the operative temperature which will satisfy most people at any given clothing and activity. The shaded areas provide information about the acceptable range around the optimal temperature. The acceptable temperature range becomes wider the higher the activity and the heavier the clothing.

In Figure 2.3 the optimal temperature corresponding to Predicted Mean Vote (PMV = 0) as a function of activity and clothing. The shaded areas inform about the comfort range ± Δt around the optimal inside temperature, which corresponds to –0.5<PMV<+0.5.

The activity in a given space should be estimated. Corresponding metabolic rates are shown in figure 2.1. The insulation of clothing worn in a space should then be estimated, and figure 2.2 shows clo values for typical clothing ensembles. The standard also provides a method for estimating the clo value of clothing ensembles from the clo values of individual garments. The clo values have been measured on a standing thermal manikin. On a person at a higher level of activity, the clo values will be lower, due to a 'pumping' effect. When a person is sitting, the chair may add 0.1-0.2 clo to the total insulation.

Using the 'met' and 'clo' values the optimal operative temperature and its tolerance limit may be read from figure 2.2. Two important examples of the application of figure 2.2 are comprised of light, mainly sedentary activity during winter and summer. This activity of 1.2 met is typical for many spaces in practice, for example in offices and homes. Typical indoor clothing during winter would have an insulation of 1 clo, while summer clothing would be around 0.5 clo. According to figure 2.2, this would correspond to a comfort range of 20-24°C during winter and 23-26°C during summer.

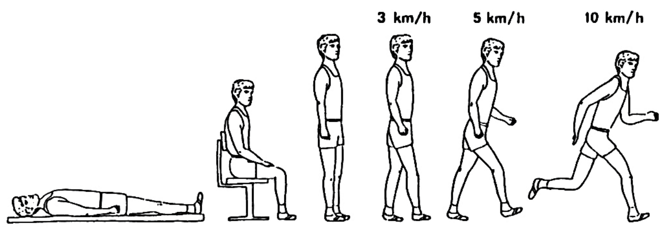


Figure 2.1 Corresponding metabolic rates of different activities (1met=58W/m²) (Fanger, 1987)

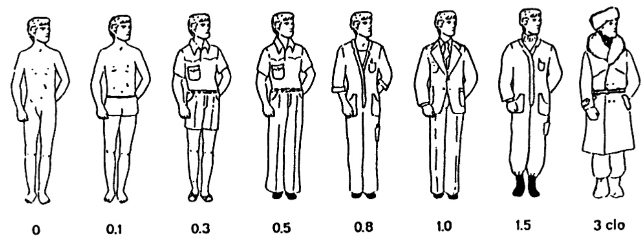


Figure 2.2 clo values for typical clothing ensembles. (1clo=0.155m²K/W)(Fanger, 1987)

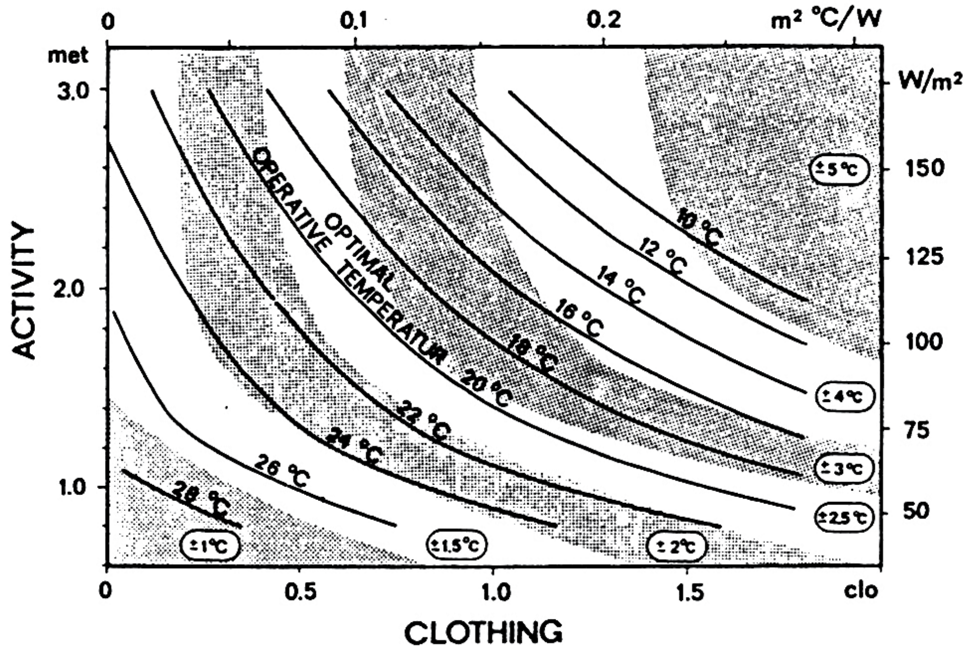


Figure 2.3 Information about the acceptable range around the optimal temperature (Fanger, 1987)

Effect of Environmental Factors on Thermal Comfort

The human response to the thermal environment depends on many environmental factors such as air and means radiant temperature, relative humidity, radiation and air velocity. The thermal sensation however does not depend on air temperature alone but rather on the simultaneous affect of four elements which must be considered together in order to assess thermal responses. To appreciate the effects of these environmental factors, it is necessary to examine each of the factors separately.

Air and Mean Radiant Temperature

The ambient air and mean radiant temperature affect heat exchange of the body by convection and radiation. The rate of exchange depends on the air velocity and the level of clothing. The body, mainly with an elevation of the skin temperature and sweat rate, responds to the rise in environmental temperature. This rate of elevation depends on the humidity level and air velocity. When the humidity level is high and the air velocity is low, (as in the case of hot summers in Cyprus) skin wetness will be experienced. But under conditions of low humidity and high air velocity, the skin may remain dry, even at high temperatures.

During the summer in Cyprus the average range of air temperatures in the shade is between 27 and 32°C, which is still below skin temperature (normally about 34°C), and so heat dissipation may still take place. But when the temperature rises above 34°C, heat

loss to the surrounding air may be difficult. Radiant heat from the sun can substantially increase the heat gain to the body. But as long as this heat gain is below skin temperature, heat loss and comfort sensation can still be achieved.

Relative Humidity

The relative humidity of the air does not directly affect the dissipation of the heat from the body but it determines the evaporative capacity of the air and hence the cooling efficiency of sweating. The evaporative capacity is determined by the difference between the vapour pressure of the skin and the ambient air. The vapour pressure of the skin depends on its temperature and ranges from about 37mmHg, under comfortable conditions (skin temperature at 33°C) to 42 mmHg in moderate heat conditions (skin at 35°C), and 47mm in severe heat (skin at 37°C). In most circumstances 42mmHg is a suitable working value.

Metabolic heat production determines the rate of sweat secretion and evaporation. When the ratio of sweat rate production to the evaporative capacity of the air reaches a value where the sweat cannot all be evaporated as it emerges from the pores of the skin, a liquid layer is formed around the pores producing an area of wet skin. At air temperatures in the range of 20-25°C the humidity level does not affect the physiological and sensory responses. At temperatures above 25°C the influence of humidity on the responses becomes apparent, especially through the effect on skin wetness, skin temperature and sweat rate. An increase in air velocity counterbalances the effect of humidity. The physiological and sensory response to humidity elevation is raised as the air velocity increases. During the hot summers in Cyprus a high humidity may cause unpleasantness because of excessive wetness of the skin and skin temperature.

Humidity has little effect on the sensation of thermal comfort when it is only moderate, i.e. between the ranges of 40 to 60%. A person engaged in sedentary work will dissipate the surplus heat easily, however in a hot-humid climate where the relative humidity remains high mostly, from 60 to 85%, it may become critical because it determines the possible evaporation rate. Moisture from the skin evaporates slowly. There are occasions when the air reaches saturation point, when the moisture on ones' skin cannot evaporate and sweat will remain sticky on the skin and may cause sleeping difficulties. This is a common climatic problem in most hot-humid climates, which can only be rectified by increasing air movement to allow evaporation to take place. Mechanical fans are the only means of providing the necessary air movement during such conditions, which are often experienced at night when the humidity is higher than during the day and the air speeds is relatively lower.

Solar Radiation

Solar radiation can affect thermal sensation significantly. Direct solar radiation falling on the body surface will activate the same sensory organs as activated by the warmth of the air. The combined effect of the solar radiation and warm air will increase the air tem-

perature surrounding the body surfaces. If the increase is higher than skin temperature, heat dissipation will be reduced. In Cyprus direct radiation occurs for a long period of time due to the absence of large amounts of clouds. A clothed human, physically active in direct sunlight, could suffer heat stroke in an environment of 27°C, at 80% relative humidity. During mid-day when solar radiation is at its peak, the cooling of the body by taking refuge under a shade of a tree may reduce the temperature of the body to below skin temperature. The air temperature under the shade is typically around 27°C.

Air Velocity

Air velocity affects the human body by increasing or decreasing the convective heat exchange of the body, which determines the evaporative capacity of the air next to the body and consequently the cooling efficiency of sweating. The effect of air velocity and air temperature on the convective heat exchange is interrelated, as convection is a function of velocity and temperature difference between the skin and the air. The affect of air velocity on evaporative capacity is interrelated to the affect of humidity, as an increase in air velocity raises the evaporative capacity and reduces the affect of high humidity.

Air speeds above 1 m/s can cause annoyance and the maximum air temperature that can satisfactorily be compensated by general air movement is about 28°C. At high air temperatures there is an optimum value of the air velocity at which the air motion produces the highest cooling. Reduction of the air velocity to below this level causes discomfort and heating by reduced efficiency of sweating. Increasing the air speed beyond the level of optimum velocity causes heating by convection. This optimum velocity is not constant, although it is dependant on the temperature, humidity, metabolic level and clothing. Air movement is an essential factor in order to achieve comfort in the summers of Cyprus. By increasing the rate of evaporation, heat dissipation of the skin is also increased. Convective heat loss takes place as long as the air temperature is less than the skin temperature.

Effect of Subjective Factors on Thermal Comfort

Apart from the main environmental factors, which affect the thermal sensation of thermal comfort discussed previously, thermal preferences are also influenced by subjective and non-quantifiable factors of individuals. An individual's discomfort is reduced by adjustment of one or a combination of the following variables.

- **Clothing ensembles:** Choosing clothes can be varied according to the discretion of the individual. He or she can exert a considerable degree of control over most forms of heat exchange between the body surface and the environment. The insulation value expressed in terms of 'clo' may range from 0.1 to 1. However the value recommended by Fanger (Fanger, 1970), suitable for the hot-humid climates, can be in the range of 0.3 to 0.5 clo.

- **Acclimatisation:** Acclimatisation to a condition in a new location influences both the metabolic rate and the blood circulation of the individual. The human body normally needs 30 days to reach full adjustment to new condition. A person in Cyprus would prefer an average room temperature of 27°C and will feel rather cool when arriving in the UK where the average room temperature is preferred at 20°C.

- **Body shape:** The rate of dissipation of body heat to the environment depends on the surface to the volume of a body. A tall thin body has a greater surface area than a short rounded figure. Larger body surface will dissipate heat more quickly. A heavier person will need cooler air to dissipate heat satisfactorily.

- **State of health:** The state of health affects the metabolic heat production. When a person is ill, heat production is increased and the tolerable range of temperatures is narrower. The body needs external means to maintain the balance such as changing external environments.

- **Food and drink:** Certain foods and drinks affect the metabolic rate. Spicy foods tend to increase the rate of sweating of the body, which may help to reduce the skin temperature.

- **Skin colour:** Light colour skin reflects more light than darker colour skins but also absorb ultra violet to a larger extent. Dark skin has more melanin pigment which helps prevent the penetration of ultra violet, which causes skin diseases and sunburn.

Psychometric Chart for Nicosia

The Psychometric Chart provides a graphic representation of the full state of the air under any condition. It relates temperature on the horizontal scale to moisture on the vertical scale. If the temperature of a given volume of air is decreased to a point at which it can hold no more moisture, it becomes saturated. The corresponding temperature is called the dew point and is shown by a curved line, which gives the chart its distinguishing shape (Lapithis, 2002).

Given any point on such a graph, a wide range of information about the state of the air can be found. These include all the major climatic indicators, dry-bulb and wet-bulb temperatures, relative and absolute humidity, vapour pressure, air volume and even enthalpy.

If hourly weather data for a location is known, it is possible to plot this on the chart as frequency data. With a range of overlays, a simple visual analysis of such information can actually tell you a lot about the characteristics of a climate.

Figure 2.5 shows a red area at its centre. This represents the comfort zone, which is based on the annual thermal neutrality temperature, Standard Effective Temperature (SET) lines at +/- 2°C either side and absolute humidity values between 4 and 12 g/kg.

When hourly data is plotted as points on the psychometric chart, and the relative ef-

fects of various passive design techniques on the comfort zone are overlaid, it quickly becomes obvious which systems are the most appropriate for any climate. This information forms the basis of the passive design analysis system. The effects of a range of passive design systems can be overlaid on the chart.

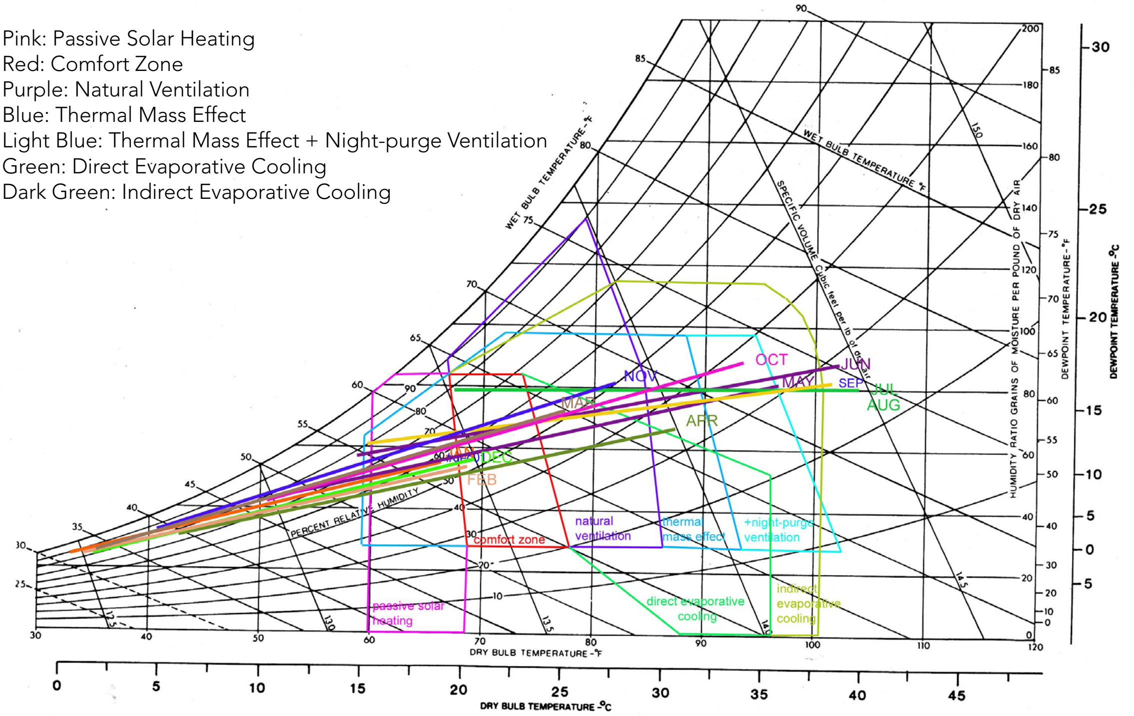


Figure 2.4 psychometric chart with the comfort zone and the yearly climatic conditions

Bioclimatic Chart for Nicosia

Olgyay Bioclimatic chart (Olgyay, 1953) is based on the best available published scientific information, some scientists would consider it as intelligent guesswork, which has never been fully validated. However, it seems to work, and both his approach and his chart had a seminal influence (Boer et al. 1985). The chart takes into account all four atmospheric factors of thermal sensation without attempting to construct a single-figure index. Such indices conceal the contribution of individual factors. In architecture and building design, the various factors may be controlled by different means, therefore it is important to be able to recognise each individually (Boer et al. 1985).

Olgyay first defines a "comfort zone" in terms of dry bulb temperature (vertical axis) and relative humidity (horizontal axis). Humidity between 30% and 65% is preferred, but under some temperature conditions it is acceptable as low as 18% and as high as 77%. Olgyay bioclimatic chart, which was originally prepared for latitude 4O°N is reproduced for latitude 35°N to suit Cyprus. According to Olgyay (Olgyay, 1963), for latitudes below 40°N, the comfort zone must be elevated by about 0.11°C per degree latitude but not beyond 29.5^{0}C. Therefore, the comfort zone is shifted up by approximately 0.5°C. Olg-

yay then examines the cooling effect of air movements and by a family of curves above the comfort zone, he shows the limits to which the comfort zone would be moved up if wind of velocity were present (Boer et al. 1985).

Olgyay method, based on a bioclimatic chart, was the first attempt to systematise the incorporation of climatic conditions into the design of buildings. It is a useful method for the assessment of comfortable and/or uncomfortable conditions likely to be found in a given environment. It also recommends the relevant comfort requirements whenever conditions are out of the comfort range. Despite its principle purpose, to evaluate the comfort criteria for both the outdoor and indoor environments, Olgyay`s method has proved its major application for the outdoor environments.

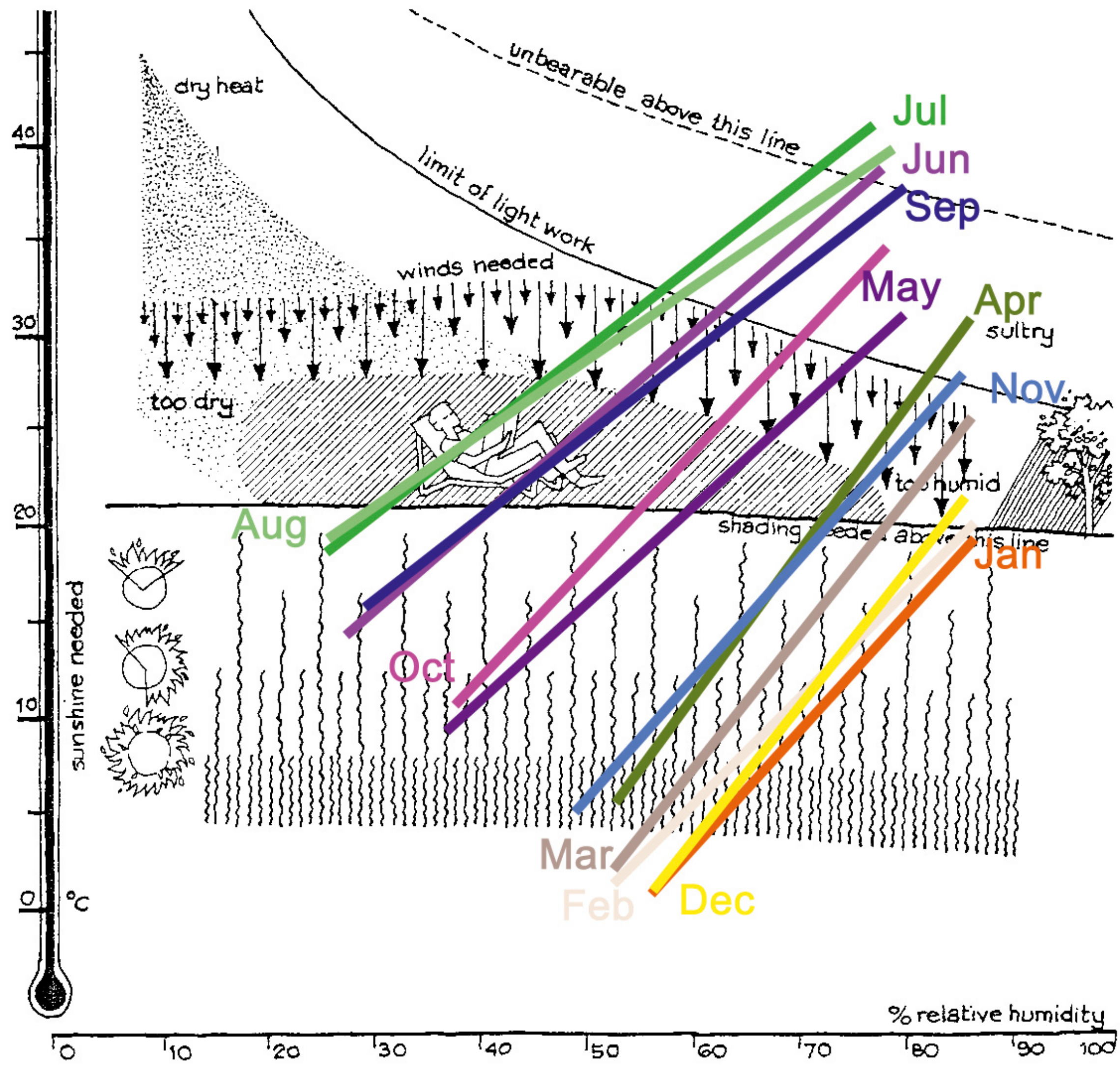


Figure 2.5 Bioclimatic chart with the comfort zone and the yearly external climatic conditions in Nicosia (Olgyay, 1963) (Lapithis, 2002)

The input of climatic data requires the mean maximum and mean minimum values of dry-bulb temperature, and relative humidity of the air (the daily and/or the monthly values). The ordinate and the abscissa of the chart indicate the scales of temperature and relative humidity of the air respectively. The comfort zone, which is given separately for summer and winter, lies from 21.5 to 28°C for summer and between 20.5 and 25°C for winter (on the corrected temperature scale). Above the comfort zone, comfort requires different levels of air movement and evaporative cooling; these are indicated by a set of curves. For the lower limits of comfort zone, the requirement for radiation and clothing are also shown. The expansion of the comfort zone upward and /or downward for various expected MRT-values is also indicated on the left side of the chart. The requirement for avoiding solar radiation is specified by the shading line below which solar radiation is necessary.

Humphreys' Comfort Chart

The human body responds to ambient temperature changes with types of activities and with the weight of clothing. The higher the level of activity and the weight of clothing, the lower the temperature desired, and vice-versa. Therefore, it is important that an optimum weight of clothing is determined, before an indoor temperature is adopted.

Accordingly, it may be a reasonable assumption to choose an optimum indoor temperature from a range that is suitable for a heavier weight of clothing and a lighter level of indoor activity like sitting and resting. Usually heavier activities such as cooking and cleaning are periodic and not all occupants are engaged in these types of activities at the same time.

Adopting an indoor temperature by the prior procedure, also ensures saving on energy consumption. Since the higher the weight of clothing, the lower the optimum indoor temperature, subsequently the energy demand for heating will lessen.

To appraise the optimum indoor conditions for Cyprus buildings, Humphreys' (Humphreys, 1971) comfort chart, based on Fanger's method (Fanger, 1970), is used. Humphreys' comfort chart uses globe temperature as the indoor comfort criteria and unlike Olgyay`s (Olgyay, 1963) and Givoni`s (Givoni, 1976) comfort charts allows for the variation of clo values (level of clothing) from 0 to 3 clo. This is the main reason why Givoni`s bioclimatic chart (especially for indoor studies) is not used in this appraisal, as this chart is based on a clo value of 1.

Figure 2.6 shows Humphreys' chart, where globe and/or dry bulb temperature (°C) is indicated on the vertical axis. Comfort zones for different clo values are shown between a pair of diagonal lines each indicating the upper and lower endurance limits for different weights of clothing under different temperature conditions and level of activity.

According to Humphreys' comfort chart, assuming clothing with a thermal resistance of 1 clo is worn, the optimum indoor conditions for a light level of activity, i.e., resting and sitting (50 and 60 met. respectively) varies between 19.5°C and 25°C globe temperature. Therefore the optimum indoor design temperature can be accepted as 22.5°C.

In this respect, an assessment of a thermally comfortable indoor condition that could be acceptable for the occupants of buildings in the climatic conditions of Cyprus forms the basic criterion in thermal analysis. The indoor thermal condition is based upon the combined result of mainly four environmental factors: air temperature, air movement, the humidity of the air and solar radiation indoors in winter. During the cold season, the indoor air movement is generally controlled to the minimum to decrease ventilation heat-loss. Therefore, the effect of the air movement may become insignificant. Thus, the indoor thermal conditions can be characterised largely by the air temperature and radiation, and to a lesser extent, by the humidity of the air.

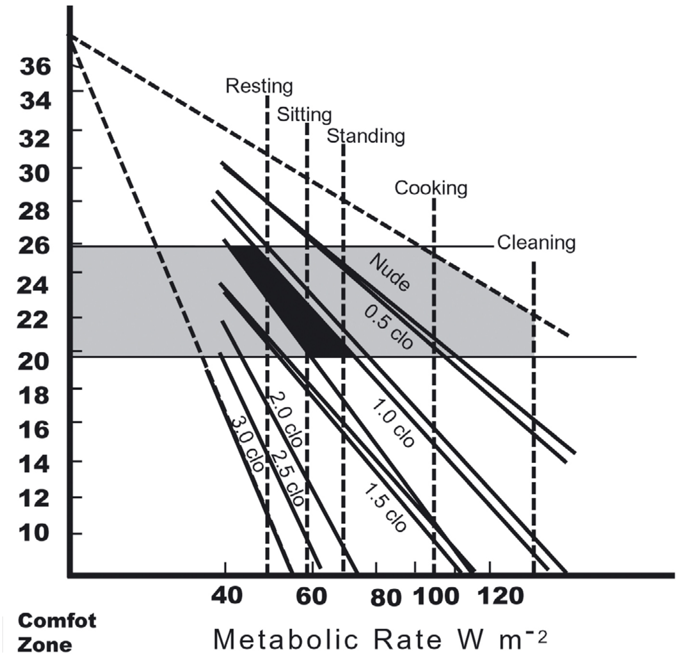


Figure 2.6 Humphreys comfort chart for the indoor conditions of Cyprus. 35°N (Humphreys, 1971)

Predicting Thermal Comfort

Thermal comfort standards are based on a mathematical model of the heat-exchange between the human being and the thermal environment (Humphreys, 1992). This model has been continually refined in laboratory and climate-chamber research so that for years it has been possible to calculate the temperature people find comfortable, if the metabolic heat generated by their activity and the thermal insulation of their clothing is known. This temperature has been shown to be, for practical purposes, independent of body-built, age, sex, race, and the climates people are used to. Moreover, if the overall heat-balance yields a comfortable skin-temperature and moisture-loss, it has been shown that it matters little what may be the combinations of air temperature, air movement, humidity and thermal radiation which provide this balance.

Tables may nowadays be consulted to find the metabolic rates for numerous common activities, and the thermal insulation of various types of dress. Computer programs or tables are available from which to estimate the “Predicted Mean Vote” (PMV) of the population from the temperature of the air, its movement and humidity, and the mean

radiant temperature of the room. The 'PMV' may range from 'cold' (-3) to 'hot' (+3). From the 'PMV', the "Predicted Percentage of Dissatisfied" (PPD) may be found. The most well known scales for the measurement of thermal sensation (response) are those of ASHRAE and Bedford, given (Szokolay, 1985)

n	*ASHRAE*	*Bedford*
+3	*hot*	*much to warm*
+2	*warm*	*too warm*
+1	*slightly warm*	*comfortably warm*
0	*neutral*	*comfortable*
-1	*slightly cold*	*comfortably cool*
-2	*cool*	*too cool*
-3	*cold*	*much too cool*

Table 2.2 Thermal comfort scales

The semantics imply that the ASHRAE scale measures a thermal sensation, but the Bedford scale brings in the broader concept of comfort. However, even the use of the ASHRAE scale requires a judgement.

Despite the comprehensiveness of the data, which is now available, and the sophistication of the mathematical model, which combines them, there are practical difficulties in using the heat-exchange model (Humphreys, 1992). The following example will show how these difficulties may arise:

- An architect designing a residential building wishes to check the suitability of the indoor temperature of the proposed building in summer-time. An intelligent guess is made at the typical summer-time clothing of the occupants, tables are consulted, and a value of 0.5 clo is arrived at. An informed guess is next made at the activities of the residents, tables are consulted, and a metabolic rate of 70W/m2 is selected. Tables of 'PMV' show that a room temperature of 24°C would be most comfortable.

- The architect then runs thermal design computer software, which calculates the indoor temperature of the proposed building from meteorological data representing a hot spell. After modifying the design to optimise the thermal performance within various other constraints, the program shows a mean indoor temperature of 26°C during occupied hours with a maximum temperature of 29°C. Consulting a table of Predicted Percentage of Dissatisfied (PPD) shows that about 70% of the occupants would be dissatisfied with this maximum room temperature.

At this point a timid designer would opt for air-conditioning. But there are other questions, which should first be asked:

- Can it be assumed that 0.5 clo is correct during a hot spell as represented by the design conditions? Would people perhaps wear lighter clothing, more permeable to moisture transfer, and so feel comfortable at a higher temperature than the 24°C suggested by the Predicted Mean Vote (PMV)? In practice, it is difficult for the de-

signer, because, although the thermal insulation of every clothing ensemble may be tabulated, it is impossible to know just what people will be wearing.

- Can it be assumed that during a hot spell the metabolic rate will remain unchanged? Perhaps people would adopt a slower pace of living and a more relaxed posture, and so become comfortable at a higher room temperature?

- Can it be assumed that the air-movement will be unchanged in a hot-spell? Perhaps people will open windows to increase the air-movement. Will they use desk-fans? If so, will they provide enough relief during the heat of a summer day? So, although the effect of any given air-velocity is accurately included in the calculation, in practice it is difficult for the designer to know what the air-velocity will be. These questions show that it is uncertain what values should be entered into the tables used to obtain the 'PMV' and the 'PPD.'

The conventional method of establishing thermal comfort temperatures depends upon the application of heat-exchange theory. It is difficult to apply to buildings at the design stage, because it requires an accurate knowledge of the clothing and metabolic rates of the occupants, and can make no allowance for the expectations of the occupant of the buildings. The method appears to give biased results both above and below room temperatures of 27°C, the direction of the bias is such as to encourage over-heating in winter and over-cooling in summer.

To evaluate the performance of different passive solar dwellings it is necessary to consider not only the thermal performance but also the 'comfort performance' of the system. In order to achieve this goal the level of comfort has been described according to Fanger's theory. The Predicted Mean Vote (PMV), Predicted Percentage of Dissatisfied (PPD) and the Temperature index are computed hourly for an inhabitant located at different places in the room. A complete set of parametric studies has been performed on two direct gain houses, one Trombe wall design and a sunspace house (Alder et al., 1984). In each case the thermal performance has been evaluated together with the comfort performance.

By considering the thermal and the comfort performance of solar houses at the same time it is possible to compare them in a more realistic way than by looking at the thermal performance only. A complete set of simulations performed on direct gain, Trombe wall and sunspace designs allow the following statements (Alder et al., 1984):

- The ultimate thermal performance of a building is rarely achieved because of comfort limitations.

- When the choice is possible, the inhabitant prefers comfort to higher thermal performance.

- It is possible to reduce energy needs and at the same time raise the comfort level by appropriate architectural design.

- Standard Cypriot massive buildings provide sufficient thermal mass and are therefore well suited for the direct gain system.

- If properly designed and constructed, Trombe wall could offer interesting thermal comfort performance under Cypriot mountainous climatic conditions.

- Changing a given house from the direct gain design to the sunspace design results in a moderate reduction of the auxiliary heat demand but raises the comfort conditioning inside the house.

Conclusion

Throughout this chapter, it is concluded that thermal comfort deeply relies on regional climate and therefore no two regions are expected to share the same comfort zone. An average of 19.5- 29°C is the proposed temperature within the comfort zone of Cyprus, with an average relative humidity ranging from 20-75%. It is however impossible to state a clarified comfort zone for any region, as psychological, physiological and practical factors are at hand.

The design of an indoor space that does not require power-driven control systems requires knowledge beyond the mechanics of passive solar systems, such as solar exposure and proper ventilation. It requires an in-depth understanding of human response to climatic temperatures within the limits of psychological and physical comfort. It is for this purpose that this chapter examined the habits of bodily and environmental thermal exchanges as well as the objective and subjective criteria for comfort in Cyprus.

In passive solar buildings in Cyprus, the floor is often used for thermal storage (due to the heavy weight construction methods used in Cyprus) and the floor temperature may therefore fluctuate considerably. Although in general this does not cause problems, temperatures above 26°C and below 20°C can cause complaints. However, if people are willing to modify their clothing during the day, then a much wider temperature range is acceptable. Good use can be made of this in passive solar buildings.

The differences between the thermal requirements of individuals should be kept in mind. The PMV predicts conditions which will satisfy the majority. However, in spaces which are occupied by only a few people, it is essential that each occupant easily modify the thermal conditions.

Draughts can often cause problems in spaces with large windows. During the night, thermal convection downwards along the cold surfaces can discomfort from air movement. Double glazing and moderate window heights will reduce these problems. Heat sources under the windows can also counteract draughts. The same cold glass, which causes draughts, can also bring (to a lesser extent) some discomfort from asymmetric radiation. The worst cases of asymmetric radiation occur, however, when people are exposed to direct solar radiation inside a building. Such situations are usually only acceptable for short periods of time.

Therefore in order to experience comfort conditions in Cyprus, it is imperative but not sufficient for buildings to be designed in accordance to the principles of passive solar architecture for the Cypriot climatological conditions. The indoor inhabitants must also

have an interactive relationship with their immediate environment. They must be conscious and aware of climatic predictions and dress and respond appropriately. They must also be prepared to perform the necessary actions on passive systems in order to attain the maximum benefits of its design.

PASSIVE SOLAR SYSTEMS

Introduction

Passive-solar systems offer simplicity, greater reliability, lower cost and a longer lifetime. Furthermore, the design of passive-solar systems is a part of the architectural design of the house, and thus, becomes an integrated element of the building's architecture. The architect, who is responsible for the building's proper function and its comfort measures, can make a competent assessment of the system's adaptation in the building's design, without interrupting the function and normal use of the building. However, the economy and the performance of passive-solar systems hinges upon the type of system proposed. Therefore, it is necessary for the architect to be familiar with the types of passive-solar systems developed so far.

The feasibility analysis of the various passive solar system uses presents a special interest both for the engineer-researcher-constructor and the consumer-inhabitant-user. The system, as far as energy is concerned, is not obligatorily or financially more advisable, while changes in macro-economic conditions can benefit or exclude the choice of some systems. When choosing a system there are also criteria of aesthetic or functionalism. It must be, pointed out that all systems are feasible, as long as the user-inhabitant takes advantage of them for at least 7 years (Chrysomallidou et al. 1992). Some of the techniques described as passive solar systems for Cyprus can be incorporated in conventional building design and planning without adding considerable cost to the construction. All that is required is intelligent design. The aim of this chapter is not to expand on the financial feasibility, but on certain points concerning Cyprus. Specified research could be done specifically on this subject.

Definitions and Elements of Passive Solar Design

Any definition of passive solar concepts should be based upon the entire set of "pathways" of natural energy exchange through a building envelope (Figure 3.1). These "pathways" can be understood in terms of the classic definitions of heating energy transfer mechanics (Howard et al. 1990):

- **Conduction:** from hotter object to cooler object by direct contact.
- **Convection:** from the air film next to a hotter object by exposure to cooler air currents.
- **Radiation:** from hotter object to cooler object within the direct path of its radiant heat waves, regardless of the temperature of the air between.
- **Evaporation:** from hotter surface to surrounding air by exposure to moisture that is thus heated to its gaseous state; also by the latent heat absorbed into air when moisture is evaporated thus lowering the sensible heat (dry bulb temperature) in the air.

The first widespread use of the term "passive" design was used to describe design concepts for the direct use of winter solar heating in buildings (Table 3.1). If such applications are properly designed, utilising the most common examples of passive techniques

which are south-facing windows and thermal storage walls, there is little or no need for pumps and fans to move solar heat, as is the case with conventional heating or "active" (mechanical) solar systems from collector to storage to building interior. But eliminating fans or pumps in a heating system is not in itself energy saving or cost-efficient and this distinction provides little justification for separating solar technology into "passive" and "active" classifications. The widespread use of fans along with separate storage in "passive" solar techniques is related to the building design and construction, its orientation, proportions, glazing and materials, whereas "active" solar techniques are related to mechanical system design (Howard et al. 1990).

		Conduction	**Convection**	**Radiation**	**Evaporation**
Winter	Promote gain			Promote solar gain	
	Resist loss	Minimize conductive heat flow	Minimize external heat flow. Minimize infiltration		
Summer	Resist gain	Minimize conductive heat flow		Minimize solar gain	
	Promote loss	Delay periodic heat flow	Promote ventilation	Promote radiant cooling	Promote evaporative cooling

Table 3.1 Design concepts for the direct use of winter solar heating in buildings (Howard et al.. 1990)

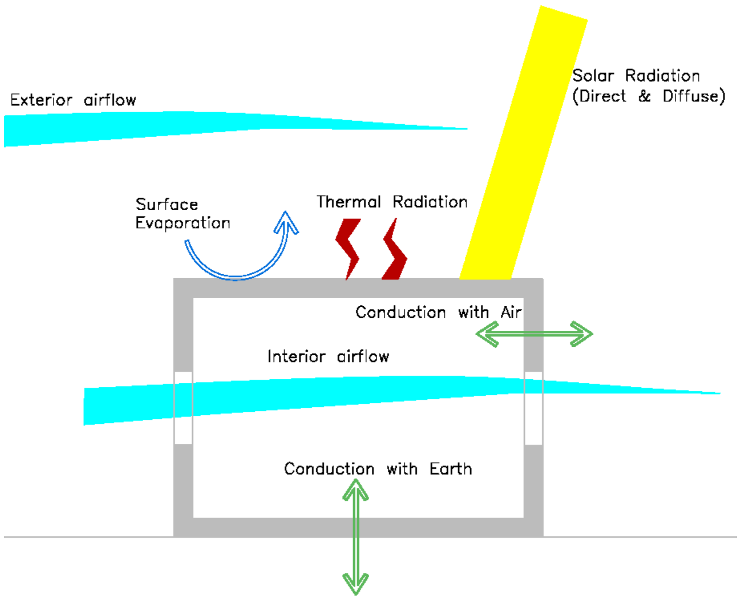


Figure 3.1 Natural energy exchange through a building envelope

Commonly available building materials and products can be used for passive solar energy applications. It is the way that these are integrated into the building design that distinguishes them as a passive energy system. This distinction between a building product or component and an integrated passive energy system is important for several reasons. It points to the critical role that must be served by the building designer who integrated the parts into a system. A qualifying passive solar energy system is defined as comprising five distinct functions (Fowler, 1981).

1. **Solar collection area** means an expanse of transparent or translucent material that is located on that side of the structure which faces south, the position of which may be changed from vertical to horizontal in such a manner that the rays of the sun directly strike an absorber.

2. **Absorber** means a hard surface that is exposed to the rays of the sun admitted through a solar collection area. It converts solar radiation into heat. It transfers heat to a storage mass.

3. **Storage mass** means a dense, heavy material that receives and holds heat from an absorber and later releases the heat into the interior of the structure. It has sufficient volume, depth, and thermal energy capacity to store and deliver adequate amounts of solar heat for the structure in which it is incorporated. It is located so that it is capable of distributing the stored heat directly to the habitable areas of the structure through a heat distribution method.

4. **Heat distribution method** means the release of radiant heat from a storage mass within the habitable areas of the structure. It provides convective heating from a storage mass to habitable areas of the structure through airflow paths.

5. **Heat regulation device** means shading or venting mechanisms that control the amount of solar heat admitted through solar collection areas.

Applicability of Passive Solar Heating Systems in Cyprus

It must be noted that the heat delivery of passive solar heating systems cannot be stopped at will, and thus a building can continue to be heated by a passive solar system even during the summer, when the system may cause overheating and discomfort. This section reviews the most common passive solar heating systems as they relate to the climatic conditions of Cyprus and considers the specifics of their applicability (Givoni, 1991) (State Energy Office, 2004). Their applicability is discussed in regions with hot summers like Cyprus, including the likelihood of undesirable overheating during summer by the passive solar systems. The three main categories of passive solar design are:

1. Direct Gain

2. Indirect Gain (e.g. Thermal Storage Walls, Solar Air Collectors)

3. Isolated Gain (e.g. Passive Solar Sunspaces)

Direct Gain

The Direct Gain system, the most common and simple design, are houses in which the living areas themselves act as collectors of solar energy by using south-facing windows which allow sunlight to directly enter the building. Thermal mass in the form of concrete or masonry walls or floors capture and store the sun's energy (State Energy Office, 2004).

Increasing the area of solar glazing in Direct Gain buildings also increases the solar gain during the daytime proportionately. It also increases the heat loss through the glazed area during the winter nights, as well as the undesirable heat gain during the summer. The ratio between these different thermal effects depends on the relative severity of the winter and summer seasons in a given region, as well as the properties and details of solar glazing. These properties are the solar transmission and thermal conductance of the glazing itself, the availability of night insulation during the winter and the solar exposure and the availability of daytime insulation (in addition to shading) during the summer. (Givoni, 1991)

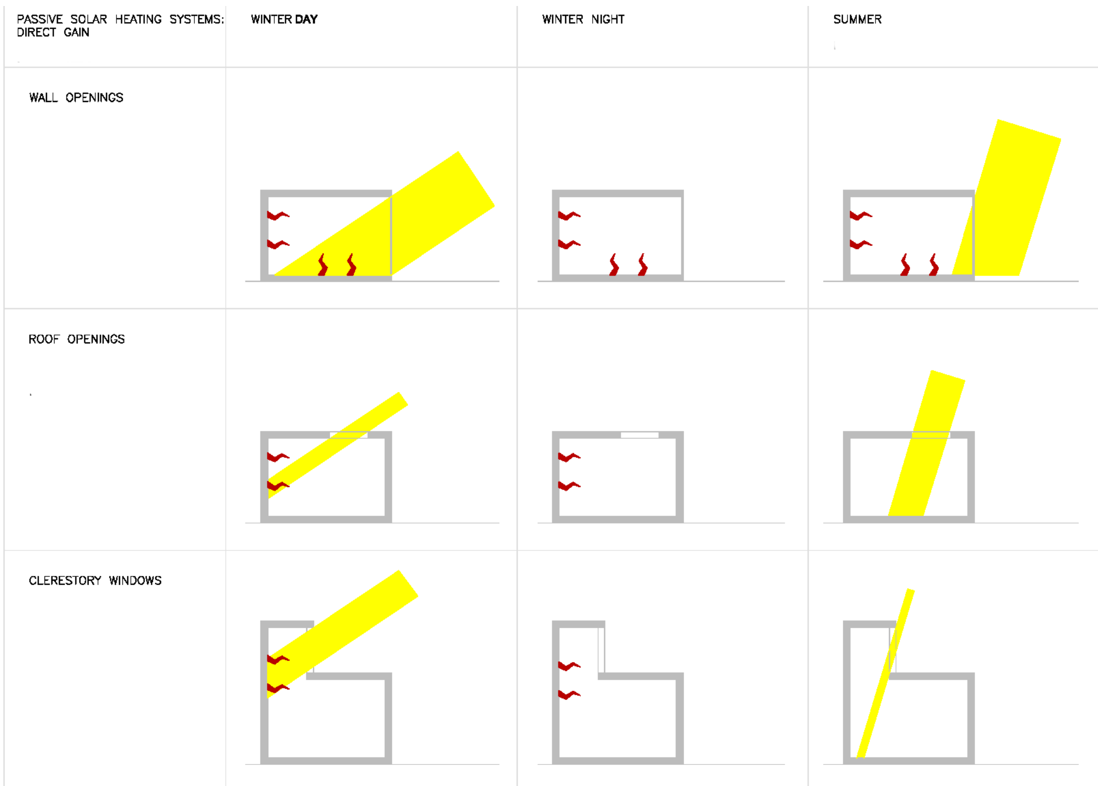


Figure 3.2 Direct Gain

Advantages

- Direct Gain concerns the significant amounts of solar energy which may be collected in heated rooms through elements which would be found in the building, in the form of windows, clerestories, and roof monitors (skylights with vertical glazing) facing the sun. Roof monitors make it possible to provide direct solar gain to rooms that do not have direct solar exposure. Therefore Direct Gain can be applied to sin-

gle storey buildings, which do not have a sun-facing wall at all.

- The two advantages of the clerestory in a direct gain system are, firstly, solar radiation is admitted directly to thermal storage on the north wall and second, the high space permits temperature stratification so that the lower occupied area is somewhat relieved of the overheating effect. The clerestory can also be used to control glare by indirect (ceiling reflected) natural lighting. In summer, the high space can be designed to serve as a thermal chimney for induced ventilation by the stack effect

- Direct Gain is the simplest solar heating system and can be the easiest to build. In many cases it is achieved simply by the disposition of windows.

- The large areas of glazing not only admit solar radiation for heating but also high levels of daylighting and good visual conditions for the outside.

- Glazing is well researched and cheap and a material that is readily available.

- The overall system can be one of the least expensive methods of solar space heating.

- With adequate insulation of the building, it is possible to rely totally on Direct Gain as a passive solar system used in the case of Cyprus.

Disadvantages

- Excessively large areas of solar glazing, in hot summers, may lead to the need of installing mechanical air-conditioning in places which otherwise do not need mechanical cooling.

- In any building heated by solar Direct Gain, the area of the southern windows would be much larger than in a non-solar building. Even if the glazing is completely protected in mid-summer from direct solar radiation, e.g. by an overhang, the diffused radiation from the sky and the reflected radiation from the ground may cause significant solar gain, in addition to the conductive heat gain. The risk of overheating is even greater in late summer (e.g. in September) when temperatures may still be high but the sun is lower making overhangs less effective.

- The simplest protection from overheating caused by Direct Gain in Cyprus (due to its hot summers) is by applying shading devices which block most of the diffused and reflected solar radiation, such as roll-able or hinged shutters outside the glazing. Another option is to block the radiation by interior insulated panels, with their exterior surface painted white.

- Large areas of glass can result in glare by day and loss of privacy at night.

- Ultraviolet radiation in the sunlight will degrade fabrics, photographs and other contents of the building.

- If large areas of glazing are used, large amounts of thermal mass will usually be

needed to modulate temperature swings that can be expensive if the mass serves no structural purpose. If the standard of thermal insulation is increased, the area of glazing required may be reduced and, hence, the quantity of thermal mass will also be reduced.

- Even with thermal mass, daily temperature swings will occur.

Indirect Gain: Thermal Storage Wall (Trombe wall) and Solar Air Collector

Thermal storage walls, also know as Trombe wall, require the construction of two exterior walls – one made of concrete or concrete-filled block and another made of glass, are more expensive than other passive solar designs. Thermal storage walls store solar heat and let it radiate into the living area. They also do not provide as much savings on heating bills during the cloudy winters (State Energy Office, 2004).

Solar air collectors absorb incoming solar energy, vent through the back of the air collector, and transfer heated air into the house. They are similar to thermal storage walls but use a conventionally framed wall and function primarily during the day. Eliminating the mass reduces the cost (State Energy Office, 2004).

The exterior surface of the wall is painted a dark colour to enhance absorption of radiation, or is given a 'selective surface' to minimise long-wave radiant heat loss. Solar radiation penetrating the glazing is absorbed within the massive walls, raising the external surface temperature and that of the air in contact with it. The fraction of the absorbed heat, which is transmitted through the wall to the interior, is determined by the thermal conductivity of the material and the wall's thickness, as well as by the combined thermal conductance (to the outdoor) of the air space and the glazing. The space behind the wall is heated by long wave radiation and natural convection from the wall's warm internal surface (Givoni, 1991).

If vents are provided, both at the bottom and at the top of the wall (vented wall), then the warm air in the air space between the dark surface and the glazing rises and flows into the building through the upper vents. Room air flows through the bottom vents into the airspace. Thus a thermosyphon air flow forms, transferring heat to the room by convection, in addition to the conductive heat transfer (Givoni, 1991).

Under optimal flow conditions, about 30% of the total energy flow in vented walls made of concrete about 30cm thick is by convection and 70% is by conduction. A vented wall exhibits a lower temperature in the air space and consequently less heat is lost through the glazing. Therefore the overall efficiency is higher by about 10% in systems with vented walls as compared with unventilated walls (Moses, 1983).

Moses (1983) demonstrated that the external surface temperature of a collection storage wall, even when the wall and a sidewalk in front of it were completely shaded from direct radiation by a deep overhang, is elevated above the ambient air by up to 8^{o}C. This elevation is caused by the diffused, and mainly by the reflected, solar radiation. In summer, and also in spring and fall, glazed solar walls may thus cause indoor heat stress.

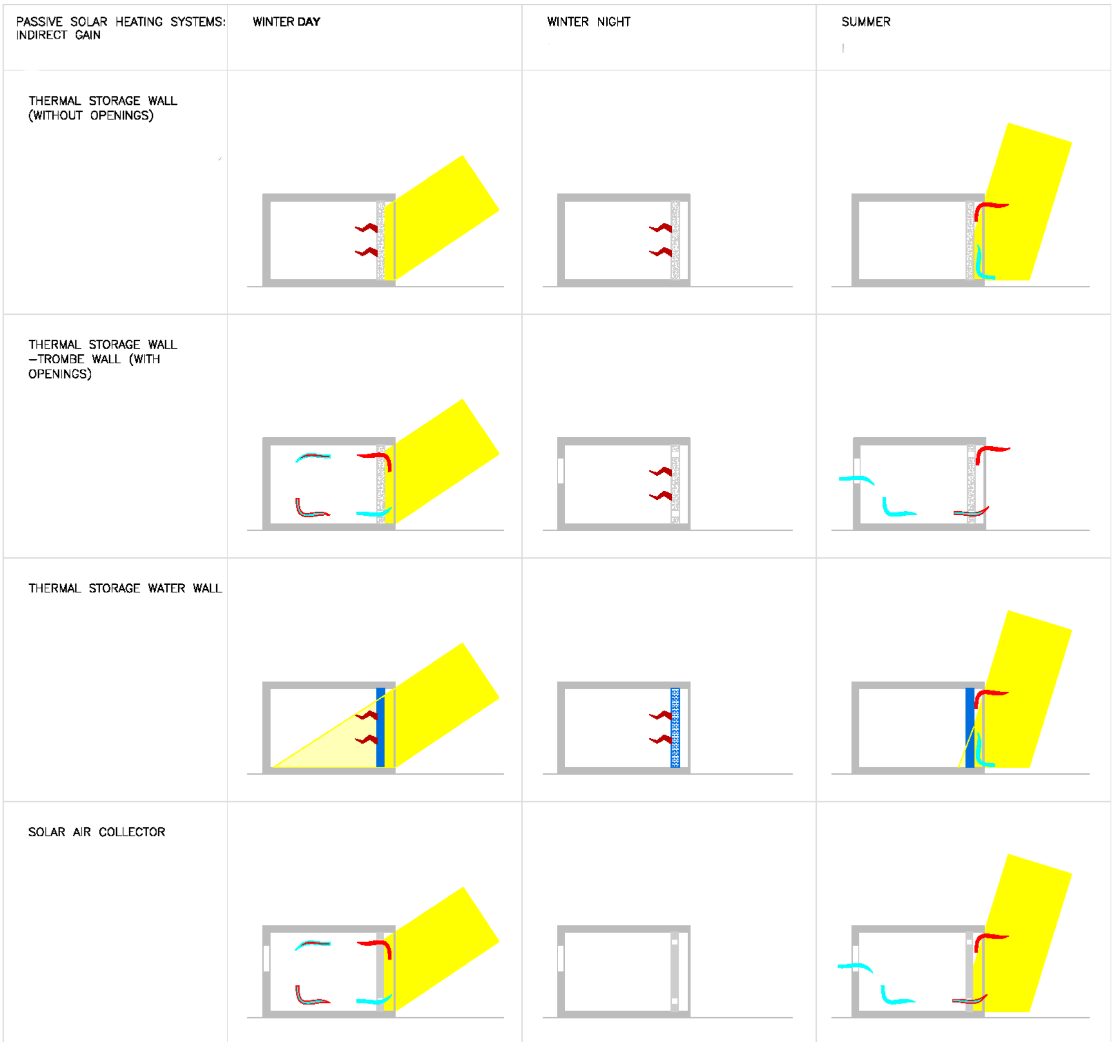


Figure 3.3 Indirect Gain

Therefore it was suggested by Givoni (1989) that in regions with sunny hot summers (like Cyprus) it is desirable to insure complete shading of the wall, not only from direct sun but also from radiation reflected from the ground. This can be accomplished only by vertical shading, e.g. by roll-able shades or by shading panels which are installed in summer and removed in winter.

During Cyprus's mild winters (Cyprus's mid-winter average temperature is about 5°C-10°C), night insulation may not be justified from the solar heating aspect. However, in Cyprus sunny summers and average mid-summer daytime temperature is above 30°C. The elevation of the external surface temperature of the glazed dark wall can cause serious overheating of the interior, and operable insulation may then be desirable. Such operable insulation will also improve the heating performance in winter.

Practically, it is not easy to equip a conventional Trombe Wall with operable insulation or even to ventilate the air space in summer. Ventilation of that space introduces dust on

the inner side of the glazing and on the dark surface of the wall, reducing the effective solar transmission and absorption. This dust cannot be removed. One way to overcome these problems is to design an accessible space, about 60cm wide, between the wall and the glazing. The extra cost of this additional space should be taken into account when considering this design detail.

Water wall variations: The "Drumwall" is an alternative thermal mass system, and has both advantages and disadvantages when compared to masonry. If the occupied space is vented during summer nights for cooling, the water wall could possibly cool more rapidly, due to the large exposed surface area

Advantages:

- The indoor temperatures are more stable than in most other passive solar systems.
- Excessive sunshine, and its associated functional problems, does not penetrate into the inhabited space.
- Installation is relatively inexpensive where construction would normally be masonry, or for retrofitting existing buildings with uninsulated massive external walls.
- If windows are provided alongside or within the solar wall then direct sun penetration provides light and quick heating of the space in the morning, while the mass is still cold.
- Glare, privacy and ultraviolet degradation of fabrics are not a problem.
- Temperature swings in the living space are lower than with the Direct Gain systems.
- The time delay between absorption of the solar energy and delivery of the thermal energy to the living space can be more of an advantage for night-time heating rather than for daytime heating.

Disadvantages:

- Summer overheating problems may outweigh winter benefits in Cyprus (with mild winters and hot summers) unless effective shading, also from radiation reflected from the ground, is provided.
- The effective heating is felt only to a depth of about 1.5 times the wall's height, due to the limited depth of natural convection air currents and the decreasing radiant heat flux from the warm sun-facing wall (Moses, 1983).
- In multi-story buildings, problems with maintenance of the glazing may necessitate the provision of access balconies. Note, however, that such balconies can function as shading overhangs for the glazing below.

- The external surface of the mass wall is relatively hot as conduction of energy through the wall is slow and can lead to considerable loss of energy to the external environment thus reducing efficiency.

- The associate controls (e.g. external insulated shutters) can be expensive.

- The south wall needs to be part glazed and part massive (Trombe wall) in order to function effectively. This configuration can have certain space and cost disadvantages.

- Discomfort can be caused at either end of the heating season by overheated air from the Trombe wall during the day or uncontrolled thermal radiation from the inside surface of either type on warm evenings. Venting can reduce these effects.

- The need for sufficient thermal mass must be balanced with the requirements for views from the living space and daylighting.

- The Trombe wall must be designed for access to clean the glazed walls.

- Condensation on the glass can be a problem.

Isolated Gain: Passive Solar Sunspaces

Sunspaces (also called Conservatories or Winter Gardens), rooms independent of the home's heating and cooling system, capture the sun's energy and transfer the heat generated to the house. Sunspaces are also used often but are usually not connected to the central heating and cooling system of the rest of the home. They are comfortable during much of the year, but are not intended as a living space year round (State Energy Office, 2004).

Sunspaces are intermediate usable spaces between the exterior and the interior of the building. Being separated from the main spaces of the building, a much greater temperature swing, (resulting from a large glazing area) may be acceptable within sunspaces, more than can be tolerated in non-isolated Direct Gain spaces. Sunspaces are not suitable in Cyprus due to overheating problems in the summer, although other factors or preferences may justify their use (Orezczyn, 1993). The sunspace is an unheated area and temperatures within this sunspace will vary greatly and so it may not be suitable for living or growing plants unless some control is used, which in the case of Cyprus, is not recommended.

Considering thermal characteristics and building design, two types of sunspaces may be distinguished (Givoni, 1991):

1. Modified Greenhouses with a glazed inclined roof and sometimes also with inclined glazed walls: This form maximises the transmitted radiation as the roof receives the winter sun-rays in late winter at a more optimal angle. However, a glazed roof gets a higher solar heat gain in the summer than sun porches, and overheating in summer

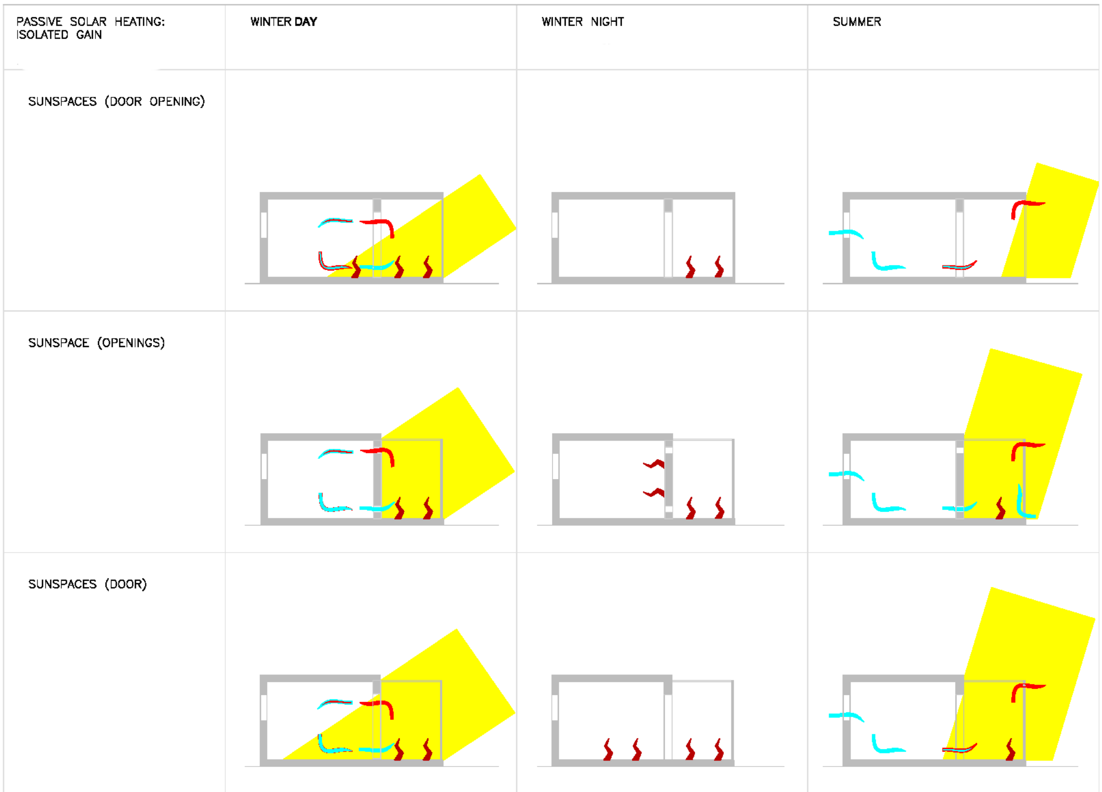


Figure 3.4 Isolated Gain - Sunspace

is more likely. This is the main reason that green-spaces are not desirable for Cyprus.

2. Sun Porches with horizontal opaque and insulated roof, where the glazing is only vertical: In this type of sunspace, the opaque and insulated roof reduces the likelihood of overheating and the large daily temperature swings caused by the overhead glazing. The potential heat gain in the winter is lower than in the case of a greenhouse type but the possibilities for control, and for year round use of the sunspace area increases greatly. This type is therefore advisable in regions with hot summers. If a sufficient portion of the glazing (e.g. 20%) is made open-able, such a space becomes (in summer) the equivalent of a shaded outdoor porch, providing shade for the building's wall behind the sunspace.

Advantages:

- They buffer the main spaces from extremes of exposure, thus reducing the potential temperature fluctuation, glare and the fading of fabrics and furniture, which may result from excessive indoor sunlight.
- They increase the heat collection potential of a given façade, by allowing a larger glazing area than is practicable and desirable with Direct Gain.

- The sunspace area itself can constitute an additional living space in the winter as well as the transitional seasons. With appropriate provision of shading and ventilation in the summer, such spaces may be pleasant environments, year round, in most climates.
- The interior "climate" of the house can be greatly improved by the addition of a thermal "buffer" between the living space and the outside air. A sunspace can run the full width of the house and the full height - reducing fabric and ventilation losses.
- Sunspaces also serve non-energetic purposes: for example an additional living space or as a greenhouse when the indoor temperatures in the winter are not low.
- Sunspaces are readily adaptable to existing houses.
- Sunspaces can be easily combined with other passive solar systems.

Disadvantages:

- The overall cost is higher and the energy collection efficiency per unit area of glazing as well as the payback period of investment in its construction is longer, as compared with Direct Gain.
- In Cyprus there are overheating problems, even in the mountains where the temperatures are lower.
- Sunspaces can experience large temperature swings.
- The glazed roof of the sunspace can be sufficiently cool at night to cause condensation on its internal surface.
- Thermal energy is delivered to the house as warm air - it is less easy to store heat from air than from direct solar radiation.
- The increased humidity caused by growing plants may cause condensation and discomfort in the building.

Isolated Gain: Rock Bed and Thermosyphon Systems

An alternate to placing the thermal mass directly in the sun is to use a rock-bed. Rock-beds are usually fan-charged. However, there are installations designed for a thermosyphon driven charging from solar collectors which are located below the building. Like a rock-bed in an active system, it can be cooled during summer nights to be available for cooling as a heat sink during the next day (Bansal et al. 1994).

Referred to as "the envelope house". A double roof and north wall and a crawl space under the house serve as a continuous air plenum. Cold air drops down the north wall, is

drawn through the crawl space in which some form of thermal storage is placed, and re-turned to the sunspace, where by displacement, the solar heated air is drawn along the ceiling to "drive" a thermosyphon loop. In none of the monitored examples was there evidence that the thermosyphon effect is sufficient to draw the solar heated air around the entire envelope and to charge the thermal mass in the crawl space. Both rocks and earth-pipes have been used in system variations. While these houses have performed

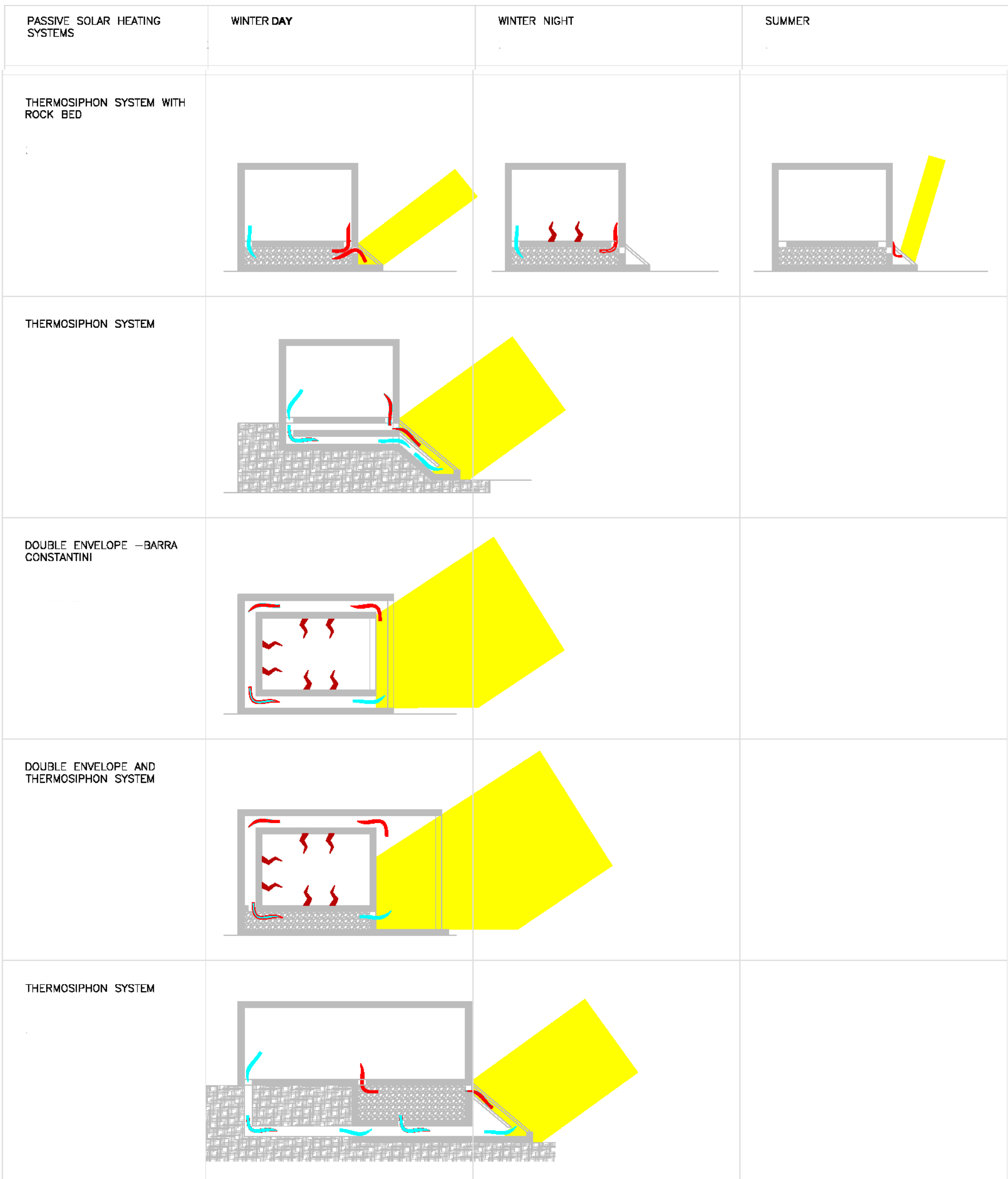


Figure 3.5 Isolated Gain - Thermosyphon System

well in terms of comfort and low energy use, the results may also be explained by the resistance insulation value of the double-wall construction (Passive Solar Update, 1981).

A thermosyphon alternative has no inherent summer cooling mode, but is of interest because it is a passive heating system with the advantages of liquid collector and storage, without relying upon pump and controller components. For the same reason, thermosyphon or passive domestic hot water collector and storage systems are preferable to active arrangements. In all of the variations, shading during the overheated period in Cyprus is necessary to prevent undesired heat gain. Any fixed shading presents the problem of blocking the sun during the spring (say, March-April when some passive solar heating is desired) in order to also block the sun during the late summer (say, July - August when the overheated period peaks). Countering overheating effects with thermal mass provides a partial solution, but not as effectively as shading devices that can be adjusted to changing seasonal needs.

Thermal Storage

Thermal storage is an essential component for the effective use of solar energy in buildings (Howard et al. 1990). It acts like a reservoir that absorbs and releases intermittent sources of energy like solar radiation (or large diurnal temperature swings) to assist in providing human comfort. Although many types of solar heating systems use remote storage (such as liquid storage tank, rock-beds, air core systems or phase change materials), this section addresses those storage techniques that are directly coupled to the interior space of buildings. The heat capacity of interior furnishings and other contents must also be considered.

Once the solar thermal storage mechanism becomes an integral part of a building's interior, it has to satisfy many criteria other than just the efficient thermodynamic storage and distribution of energy. Thermal storage and release has to occur within an acceptable temperature range for human comfort. Thermal storage materials properly used may enhance human comfort. The thermal storage may also become part of the interior aesthetic of a building in which it is employed.

In addition to the interior design considerations of the owner or operator and the amount of storage required for good performance and comfort by the climate energy source, there are other important internal sources of energy that can influence the design of any storage system. The frequency and quantity of internal heat gains supplied or generated by occupants, lights, equipment, and appliances can be as important as the amount of solar energy available. The daily and weekly pattern of occupancy along with the local utility rate structure may determine (for the designer) whether interior thermal storage is an appropriate energy conservation strategy or not, and will greatly influence design constraints.

Thermal mass can be incorporated into a passive solar room in many ways, from tile-covered floors to masonry walls. When selecting thermal mass materials, consider the aesthetics, costs, and energy performance.

- Slab-on-grade floor are used in most passive solar homes. Slab floors can be stained or stamped into a variety of patterns or finished with tile, stone or brick.

- Interior mass walls are solid mass walls between interior rooms. Since they have living area on both sides, they can be up to 30cm thick, although thinner 10-20cm walls deliver heat more quickly (State Energy Office, 2004).

- Thermal storage walls are solid masonry wall fronted by exterior double-glazed windows. Sometimes known as Trombe walls, these designs are one of the least cost-effective passive solar options. They are expensive to build, and many researchers question whether the mass wall has sufficient time to warm between the periodic spells of cloudy weather (State Energy Office, 2004).

- Water-filled containers are water stores heat twice as effectively as masonry by volume and five times as effectively by weight. Commonly used water containers include fibreglass cylinders and 100-200 litre metal drums (State Energy Office, 2004).

- Hot tubs, saunas, and indoor pools are some homeowners have tried to use hot tubs, saunas, and indoor pools as thermal storage mass. In most cases, these forms of water storage do not work well. The desired water temperature for comfortable use of these amenities is hotter than the passive solar contribution can possibly achieve (State Energy Office, 2004).

Thermal Storage Process

The process of sensible heat thermal storage obeys the laws of thermodynamics, which state that energy flows from a warmer source to a colder (sink) object (Howard et al. 1990). Conduction, convection, or radiation, or combinations of the three transfer the energy. It is useful to think of the process of thermal storage in three parts.

1. First part involves the collection or the absorption of energy by the storage material. In the case of solar energy (radiation) this occurs when the sun directly irradiates the storage materials and its surface is heated according to the amount of energy that is absorbed, reflected, re-radiated, or convected. The absorption of radiant energy is a function of the absorptivity of a material's surface. Collection of energy can also occur when the air in a room is heated by convection from sunlit surfaces elsewhere, and heat is transferred to the storage material, walls, floors, or ceilings. Usually, the rate of transfer by natural convection is comparatively slow. It is obvious that the rate of flow and therefore the transfer coefficient can be greatly increased by creating 'forced' convection, such as the use of fans. However, measurements do show that remarkable quantities of air convect in passive solar buildings, from source to sink zones, without mechanical means.

2. The second part concerns the distribution of energy once it has been absorbed. It may be either convected or re-radiated back to the room air and hence to the environment, or it may be conducted into the storage material. The rate of transfer into or out of storage mass is determined by the thermal diffusivity of the storage material's conductance, specific heat, and its density. These properties control the dynamic flow of energy into and

out of the storage medium, (i.e., the "pulse" per wave of energy) and should not be confused with the total heat capacity of the material, which is a static measure based on the material's total thickness, conductance, specific heat, and density.

3. The third part involves the release of energy. Once the storage material has absorbed enough energy it will be warmer than its surrounding environment, or radiation and natural convection. This process is controlled by the material's physical properties of emittance, thermal diffusivity, the temperature difference between the surface and the surrounding environment, and the convection coefficient created by the air flow over the surface

It should be pointed out that interior thermal storage does not increase or decrease the total energy available, nor does it change the long-term heat loss/gain of the building. Thermal heat capacity in exterior envelopes however, can reduce the energy demand on space conditioning requirements under mild heating and cooling climate conditions such as Cyprus. It changes the pattern of energy flow, i.e. the timing and amplitude of energy flow (volume). These energy balance modifications have been described as time lag (as a result of the heat capacity of the material) and amplitude reduction (primarily as a result of the conductance and diffusion of energy within the material). The time lags may be designed into buildings to displace periods of low envelope energy that can be used more effectively. Amplitude reduction is used to lower the peak differentials (usually temperature) that the mechanical space conditioning must handle (Figure 3.6) to produce the desired level of comfort (Marad, 1980).

A construction with a low thermal value (air-to-air transmittance) will reduce all forms of conduction heat transfer through the building envelope. Such a conduction heat flow would be large, if the temperature differences were large. With small temperature differences between the outside and the inside, the heat flow would be small, and an improvement in thermal insulation would not bring any significant reduction.

However, it is worth remembering that in a heat gain situation, with strong solar radiation, it is the surface temperature value that must be used to find the temperature difference, thus even if the air temperature difference is small, the actual temperature difference acting as a motive force for heat flow may be large, and insulation may be important.

Knowledge of the decrement factor and time lag for different materials, thickness and combinations of materials in various constructional elements, is important for the designer. The aim is to permit heat gain through the enclosing elements when there are heat losses through other channels (e.g. ventilation). Avoid such heat gain when there is already a surplus of heat flow into the building. The selection of construction with an appropriate time lag is an essential factor in the design. Figure 3.6 shows the time lag for different roof constructions (Marad, 1980).

The question is how much thermal capacity and what length of time lag is desirable? A point often overlooked is that the thermal capacity can be too much; the time lag can be too long. For example, a wall facing east receives its maximum heating at 10.00 hours. A time-lag of 10 hours would put the inside surface temperature maximum at 20.00 hours, when it is likely to be too hot and the occupants may want to sleep.

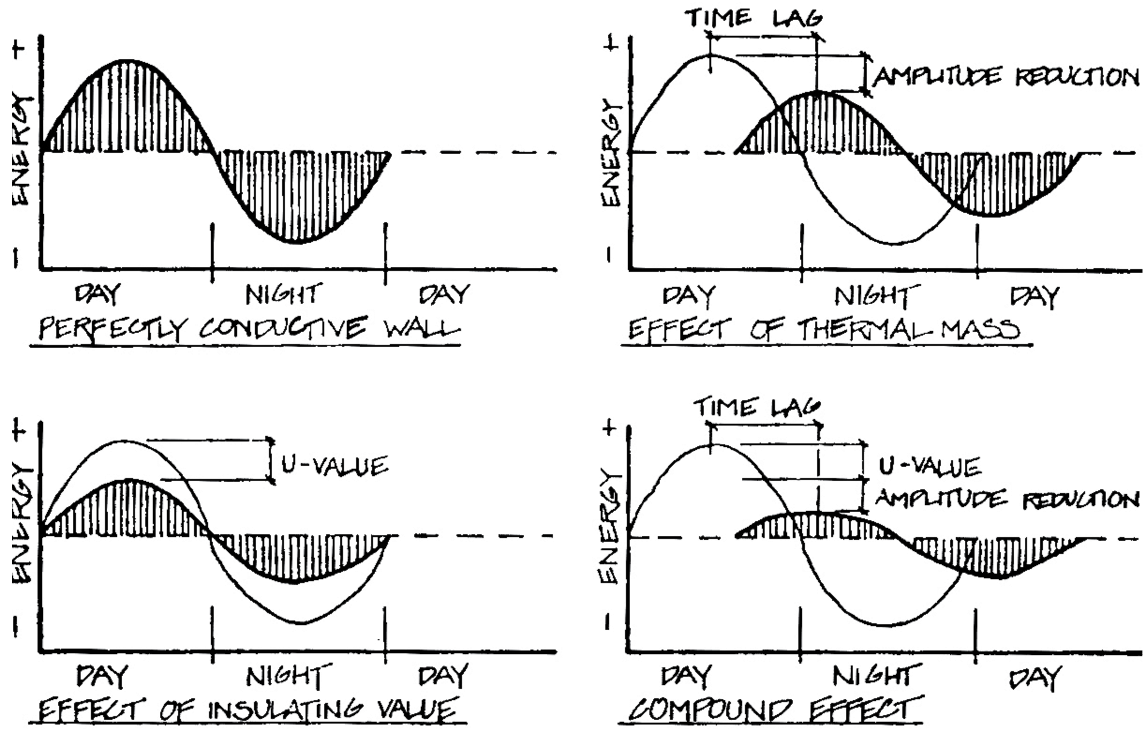


Figure 3.6 Time lag and amplitude reduction (Marad, 1980)

Heat Capacity

Mazria (1979) provided classic rule-of-thumb heat storage guidelines from which numerous 'first-generation' passive solar buildings were designed. A summary of these guidelines is shown in table 3.2 for several different passive solar system types. Monitored data shows that homes designed with these rules perform fairly well, but that problems can occur in the application of these rules to multi-zone or internal-loads-dominated commercial, industrial, or institutional structures.

Average outdoor temperature °C	m² of window needed for one m² of floor area	m² of wall needed for each one m² of floor area		m² of greenhouse glass needed for each one m² of floor area	
		Masonry wall	Water wall	Masonry wall	Water wall
11.1°C (Winter)	0.24-0.38 (with night insulation)	0.60-1.0	0.45-0.85	0.9-1.5	0.68-1.27
22.2°C (Summer)	0.13-0.21	0.28-0.46	0.20-0.34	0.42-0.69	0.30-0.51

Table 3.2 sizing solar windows, thermal storage wall and the attached greenhouse (Mazria, 1979)

The Los Alamos Diurnal Heat Capacity (DHC) method refined by Balcomb (1983) (Figure 3.7) is a very simple and useful method for the analysis of storage components as

well as the total interior effective heat capacity of a passive design. DHC can be used to estimate the role of all interior surfaces, whether lightweight or massive, and their properties, in temperature swings and comfort levels to be expected. Each type of surface is also characterised in terms of its exposure to transmitted solar radiation via the collection system to make the necessary calculation.

A basic finding is that the density of the specific heat storage material has a major effect on optimal thickness and effective storage capacity. An optimal storage material would have relatively high density, a specific heat above 263.76kJ and reasonable, but not excessive (overly rapid) thermal diffusivity. The thermal diffusivity is expressed as the conductivity divided by density times specific heat. For common heat storing structural materials, thickness greater than 150-200mm has little added effect on diurnal heat storage. Lighter weight materials for heat storage are optimally thinner, and much less effective.

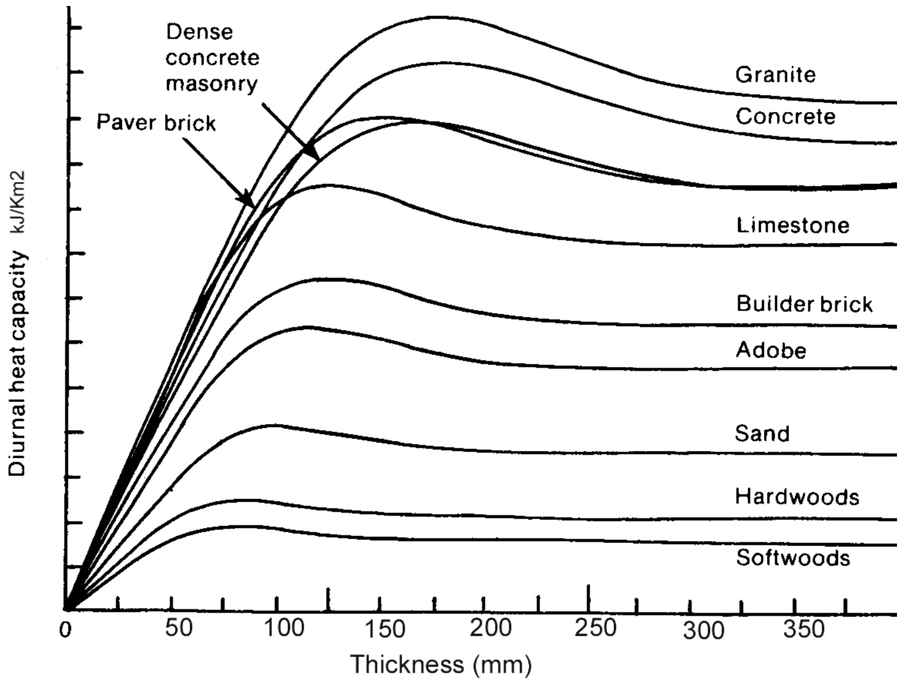


Figure 3.7 Diurnal Heat Capacity (DHC) responsive thickness of materials versus heat capacity (Balcomb, 1983)

Mass Applications

Construction of passive solar heat storage ranges from the very simple to the complicated. The simplest heat storage approach is to construct the building of massive structural materials insulated on the exterior to couple the mass to the indoor space. Multiple functions of the components can increase cost effectiveness. Heavy weight construction is suitable for all climatic regions.

Research has discovered important physical and thermal relationships among the level of envelope insulation, the size of solar aperture, and heat storage requirements (Howard, 1990). If the mass of exterior envelope is elevated, then a change in the amount of

interior, and transmitted solar gains must be carefully reconciled. As more energy using (heat generating) equipment and persons are added to the interior, the requirements for solar heat are decreased, and the need for cooling increases and becomes less 'seasonal'. Addition of thermal mass can help control transient thermal discomfort if coupled with controlled ventilation.

If a very highly insulated envelope is designed, with little thermal mass inside, care must be applied to avoid using too much glass as a passive solar collective area. Research at Los Alamos, confirmed by monitored results, indicated that about 8% of floor area in south-facing windows was the limit for low-mass well-insulated houses. For Direct Gain systems, south-facing window areas greater than about 10-12% of floor area require thermal mass, well distributed over floors, walls, and ceilings, to reduce temperature swings. The designer should first provide adequate view and natural lighting with moderate Direct Gain glass areas; then if more heat is needed from passive solar, the designer should consider indirect heating such as thermal storage walls, sunspaces, or isolated gains systems.

The aspects relating to mass are of particular significance for Cyprus due to the large diurnal fluctuations (15 to 25°C), and the potential possessed by mass for large solar contribution in winter and cooling in summer (Sergides, 1991). This implies that heat admitted during the day, during the winter, could be stored for use during the evening hours and in the summer it could be decapitated in the cool night.

The addition of mass has already been examined in relation to the shape of a house (Rectangular, L Shape, ∏ Shape, Square) (Sergides, 1991). The study has shown that addition of internal mass incurs energy conservation of varied extent according to the thermal behaviour of each shape. On the contrary, addition of external mass leads to higher energy consumption in all shapes. Whereas masonry provides a good heat storage medium within a space, it readily passes this heat to the outside when added on exterior walls.

Another possible reason could be the quantity of the mass. From studies (Sergides, 1991) it appears that the extent of mass increase seems to be critical concerning its effect on the energy loading. Extensive increase of internal mass could act adversely in as far as time needed to cool it summer nights or indeed heat it in the winter.

Interior mass in Direct Gain systems with layers greater than 150mm of solid concrete (or equivalent material) may even be counterproductive. Direct gain floor systems should receive direct sun and be well insulated on its perimeter at least. About 100mm thickness is correct for concrete masonry paves, brick paves, and cast concrete floors.

The internal partitions should be placed in such a way that they do not obstruct the air movement between the north and south windows. This is necessary for natural cooling during summer nights (Kolokotroni, 1985).

Monitored results (Howard et al. 1982) (Frey et al. 1982) (Hasking et al. 1979) point to Direct Gains being most effective in standard construction (no added mass, insulated light frame walls) when solar glazing areas are less than 8% of the interior floor area.

Above this ratio, added mass is needed either in the form of heavier envelope construction or added interior thermal storage systems. Measured data point to the wisdom of using Direct Gains in smaller amounts, combined with indirect or isolated gains systems for heat, after the daylighting requirements are satisfied. Trombe walls, sunspaces with high-mass separation walls, or air-core type systems can satisfy this requirement.

In a Trombe wall, different criteria exist to determine optimal thickness. In Trombe wall design, it is necessary to relate the heat output desired from the wall's interior face to the wall's thickness, under typical operation conditions. Clearly, the use of typical masonry units of 150-300mm (depending on density) is warranted. Thicker walls than this may again be counterproductive according to the data. Certainly for a typical masonry Trombe wall, annual solar heating fractions do not increase much beyond a 200mm thickness (Figure 3.8). A more important concern regarding wall thickness here may be structural or seismic code requirements for life safety. However, most Trombe walls are reinforced, and many are filled with concrete or grout to increase their heat capacity. This improves structural integrity as well.

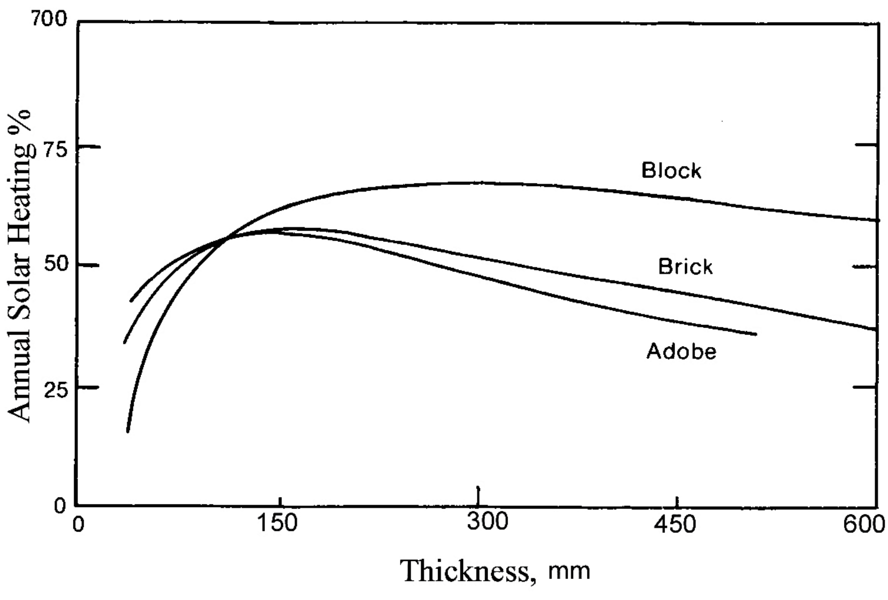


Figure 3.8 Trombe wall thickness vs annual solar heating percentage (Balcomb, 1983)

Occupants of passive buildings must be well informed of the necessity for exposure of thermal storage components to direct sunlight, or to secondary gains via reflection and convection. There have been examples of follow-up owners covering heat storage walls with insulation and wall-board to "hide" block or brick exposed on the interior, thereby eliminating its storage function. Placement of thick carpet over heat storage floors and hanging too many plants in sunspace windows are other examples. There is a limit to the positive effect interior mass can have on comfort if it is shielded from effective solar heat absorption. One way to prevent this kind of intervention is to provide a storage mass that is aesthetically acceptable. Also, an operator's manual for the building explaining the functions and requirements for the mass to work well can be helpful.

Occupants may be unable to accept the appearance of certain passive solar components. For example, PCM rods exposed in a sunspace may look “high tech” but occupants may not feel they fit with traditional furniture. An interior designed for thermal performance and comfort may not help “sell” the building if it does not look good to the owner/buyer. Interior masonry has been successfully associated with commercial or institutional buildings, and exposed mass in this setting, as opposed to residences, may be deemed more acceptable.

A solution to improve appearance is to cover heat storage materials with no insulating finishes such as grass cloth, plaster or wall paper. New architectural patterns for masonry surfaces provide new opportunities for exciting interior design that do not compromise the comfort and performance of the passive solar system.

In the 70’s the spatial arrangement, and even the exterior shape of the building were thought related directly to performance. This was true in the earlier passive designs where less attention was paid to envelop thermal protection and the emphasis was more on ‘glass and mass’. The new passive solar design ethic can be applied to virtually any design, and proper analysis indicates that insulation, windows, mass and arrangements of these components produces good results.

Thermal Insulation

There are frequent debates between advocates of super insulation of residential building envelopes and those who favour solar applications of one type or another. Obviously, the implications of these different strategies on envelope design are significant. The primarily opaque walls suggested by the super insulation approach are in marked contrast to the glazed façades of many of the solar strategies (Prowler et al. 1990).

A study done by LANL Solar Group (Balcolmb et al. 1984) concluded that, for a given climate, there is an optimal mixture of energy supply by passive solar techniques and reduction of energy demand by insulation. This optimal mixture depends on the relative costs of the solar system and the insulation, but not on fuel costs. In cold, cloudy climates almost all of the energy-savings investment should be spent on insulation. The reverse is true in milder, sunny climates like Cyprus.

A study conducted by Serghides (1991) regarding the extent of insulation applications for Cyprus concluded that the introduction of insulation improves their efficiency and their energy consumption, for both heating and cooling decreases. The interception of the sun at the very external side of the buildings’ skin in the summer results to the efficiency of external insulation for cooling energy conservation. In the winter, with the positioning of the insulation on the external side, heat stored in the thermal mass of the structure is utilised by storing the trapped solar energy and prevents the stored heat to be conducted rapidly to the outside. The introduction of insulation on the roof presents a high percentage of energy savings; 15% for heating and 45% for cooling.

Another study conducted by Kolokotroni (1985) informs that thermal insulation should be provided to reduce heat losses in winter and heat gains in summer. It should be

placed as externally as possible because the part of the wall or roof inside of the insulation determines to a large extent the effectiveness of the heat capacity. The optimum U-values are 0.2 W/m²K for the mountainous climatic regions, 0.6 W/m²K for the inland climatic regions and 0.9 W/m²K for the coastal climatic regions.

Building Shape and Orientation

Among the earliest questions asked was how should the solar aperture be oriented to collect maximum solar radiation? In reply windows of acceptable solar orientation and tilt were soon articulated (Prowel et al. 1990). A window of 15° on either side of due south was generally accepted as the rule of thumb for acceptable collector orientation in most locations.

The rule of thumb for optimal tilt (the angle between the collector and the horizontal) for active solar domestic hot water (DHW) collection was determined to be equal to the latitude angle at which the installation was located. Thus, the collector in an active DHW system for Cyprus, whose latitude is approximately 35°, would be best tilted at 35° to be the horizontal.

For space heating, the optimal tilt was determined to be the latitude plus 15°. The penalty for deviations up to 20° from these optima was found to be modest. In fact, calculations showed that vertical surfaces with additional reflections from snow or reflectors in the foreground would intercept almost as much radiation during the heating season as optimally sloped surfaces. This supported the case for the many vertical-wall passive solar homes that were constructed throughout the period. Pitched roofs should be constructed where the precipitation levels require them, i.e. the mountainous climatic region.

Clearly, the greatest and most immediate source of heat gain to a building's interior is the solar radiation entering through a window. This could increase the indoor temperature far above the outdoor air temperature, in Cyprus, as a result of the greenhouse effect. Window glasses are practically transparent to short-wave infrared radiation emitted by the sun, but almost opaque for long-wave radiation, emitted by objects in the room. The consequence of this is that the radiant heat, once it has entered through a window, is trapped inside the building. If solar overheating is a problem, as it is in Cyprus, there are four methods available for the reduction of solar heat gain through windows. These four variables are within the designer's control:

1. Orientation
2. Glazing
3. Internal shading devices
4. External shading devices

By plotting the directions of maximum radiant gain for both hot and cool months, it is possible to determine the optimum orientation for any given location. It is unlikely that the two directions will be at right angles to each other and some compromise must be made to achieve the most satisfactory distribution of total heat receipts in all seasons. It is difficult to generalise, but as east and west facing walls receive the highest intensities of radiation they should normally be kept as short as possible and openings, if they must exist on these sides, should be as small as possible. The west side, which receives the maximum radiation during the hottest part of the day, can be particularly troublesome.

The shape of the house (Kolokotroni, 1985) (i.e. aspect ratio) affects only slightly its thermal performance when average weather prevails and it is designed and used in an 'optimum' way. Under extreme temperatures and solar radiation in winter, a relatively compact design is less sensitive to changes than the same floor area but with an elongated across the East-West axis, because less heat is lost through the smaller external surfaces and windows. Thus, less energy is required to establish internal comfort in winter. In the summer however, the compact design performs slightly worse under average and extreme temperatures.

Sergides (Sergides, 1991) compared four shape variations (Rectangular, L Shape, Π Shape, Square) when summing up energy consumption in both heating and cooling. It is observed that the square shape retains its lead in being the most economical house. The addition of internal mass (Sergides, 1991) combined with the maximisation of south glazing, increases energy conservation in heating for all four shapes. The rectangular shape presents the highest amounts of savings. This difference is attributed to the greater extent of south glazing increase in this shape.

Glazing

Material research has focused on glazing, since windows usually create an adverse impact on building operating costs. Energy penalties caused by low insulation values and uncontrollable solar gains often outweigh energy benefits, such as daylighting. Nevertheless, windows provide essential benefits, such as view, ventilation, and a psychological (and sometimes physical) connection to the outdoors. Perhaps more importantly, windows are architectural elements that can set the style of a building. Any new glazing alternatives must provide all these benefits to be accepted in the marketplace.

There are two approaches for improving energy performance in residences that require wintertime heating during some part of the year. Improve the solar transmission while maintaining the thermal insulation level, or improve the thermal resistance while maintaining the solar transmission. Either approach greatly enhances the window as a south-wall collector, and if the improvements are large enough both approaches can be used, as an effective cloudy-day or north-facing solar collector, since the diffuse solar radiation can be effectively trapped (Neeper, 1982).

The use of double-glazing is an effective means of controlling heat losses and therefore reducing energy consumption. By replacing all single glazing with double there is about 48% energy savings (Sergides, 1991). Today's commercially available argon-filled

low-emissivity (low-e) windows can attain performance about midway between the extremes of the other glazing materials.

More of the openings should be placed on the south wall in order to promote direct heat gains in winter (Kolokotroni, 1985). The optimum percentages of south wall openings are 40% for the mountainous, 24% for the coastal and 18% for the inland climatic regions. Small north windows should be opened to enable cross ventilation in summer but not waste energy in winter. A value of 5% north wall windows is sufficient for adequate cross ventilation during summer nights.

Internal Shading Devices

Internal blinds and curtains are not very effective means of solar control, especially in Cyprus. It is true that they stop the passage of radiation, but they themselves absorb the solar heat and can reach a very high temperature. The absorbed heat will be partly convected to the indoor air and partly re-radiated. A percentage of this radiation is outwards (depending on the type of glazing), but as it is of long wavelength, the window glass stops it. The usual narrow space between the window and the blind will thus be quite substantially overheated, unless ventilated to the outside air. The hot surface of the blind causes the indoor Mean Radiant Temperature (MRT) to rise above the air temperature. Such blinds are most effective when fitted between sheets of double-glazing. Internal shades are very often of the venetian blind type and for these to give most benefit, they should be adjusted so that they reflect the rays of the sun back to the outside so that no direct rays pass between the blades into the room.

External Shading Devices

The impact of solar radiation on buildings in hot climates must be reduced not only by orientation and effective design of the structure, but also by adequate shading. Although it is not always convenient or economical to shade roofs, walls lend themselves to the treatment in a number of ways that can be invaluable for eliminating or reducing one of the greatest sources of heat gain; the solar radiation entering through the windows. Various methods are available for screening walls and windows, and when deciding the shading requirements, each facade must be separately considered to achieve the most effective solar control.

Building external shading devices can be:

1. Movable

2. Vertical

3. Horizontal

4. Egg-crate

Movable Shading Devices

Movable shading devices can be provided so as to shade the house during summer days but not in winter. Closing the shutters at the appropriate time improves the U-value of the house and protects it against solar radiation. Full shading is preferable in summer, and in any case shading of the south wall is essential (Kolokotroni, 1985). The introduction of shutters to intercept the summer sun, incurs considerable reduction of cooling (Sergides, 1991). The introduction of shutters and addition of overhangs and side-fins also concludes to considerable reduction of cooling (Sergides, 1991). The total savings are 20% for both heating and cooling.

Vertical Shading Devices

Vertical shading devices consist of louvre blades or projecting fins in a vertical position. The horizontal shadow angle (HSA) measures their performance. Narrow blades with close spacing may give the same shadow angle as broader blades with wider spacing. It can be seen that this type of device is most effective when the sun is to one side of the elevation, such as an eastern or western elevation. For a vertical device to be effective when the sun is opposite to the wall considered, it would have to give almost complete cover of the whole window.

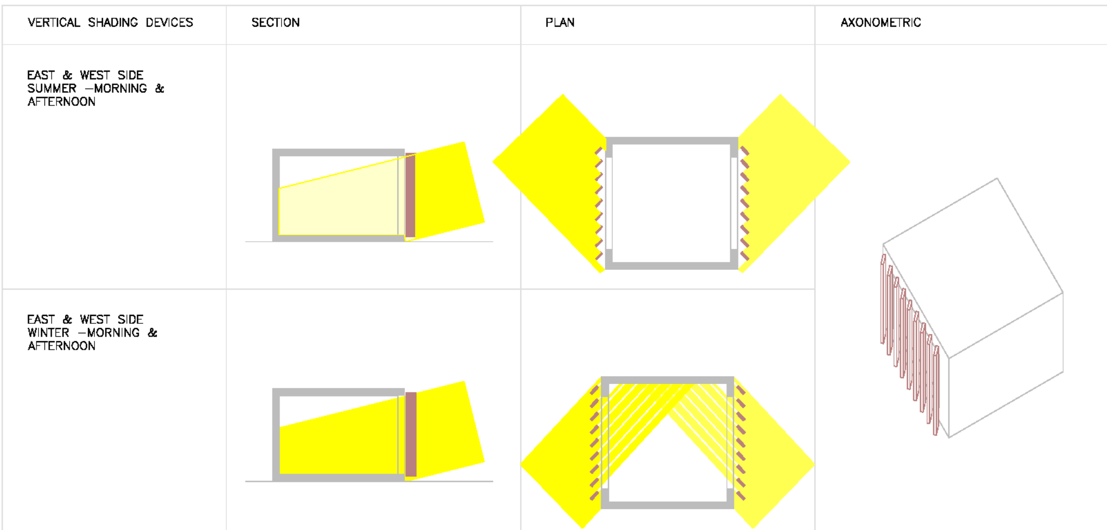


Figure 3.9 Vertical shading devices

Horizontal Shading Devices

Horizontal devices can consist of roof overhangs, canopies, balconies, horizontal louvre blades or externally applied venetian blinds. Projecting slabs are also common forms of horizontal screening. Their performance is measured by the vertical shadow angle (VSA). These are more effective when the sun is opposite to the building face and at

high angle, such as for south facing walls. To exclude a low angle sun, this device would have to cover the window completely, permitting a view downwards only.

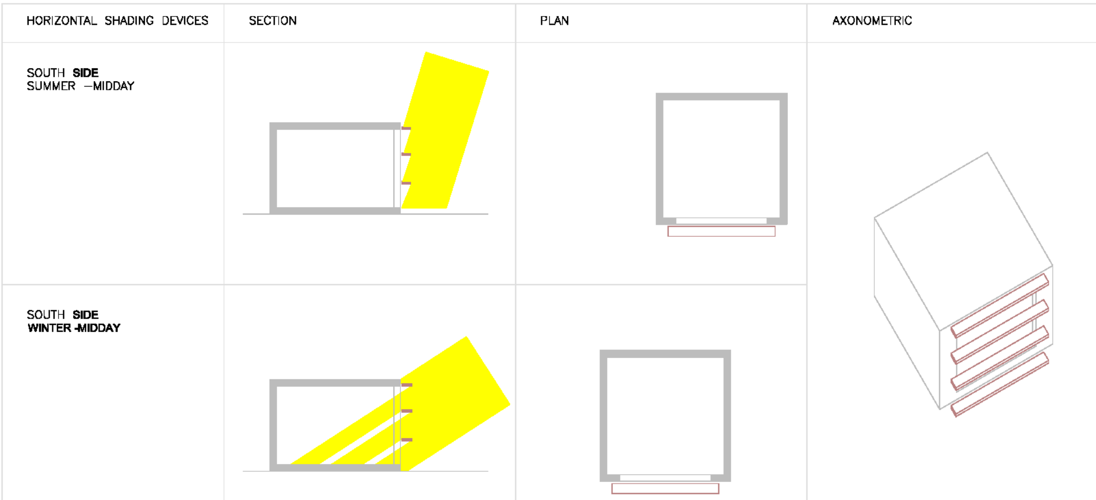


Figure 3.10 Horizontal shading devices

Egg-crate Shading Devices

Egg-crate devices are combinations of horizontal and vertical elements. The many types of grille-blocks and decorative screens fall into this category. These can be effective for any orientation depending on the detailed dimensions.

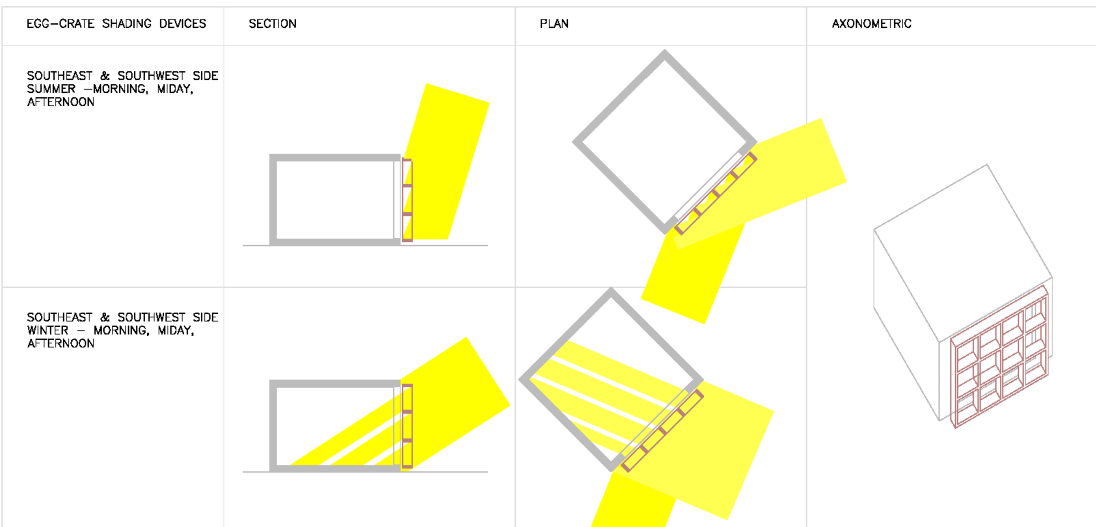


Figure 3.11 Egg crate shading devices

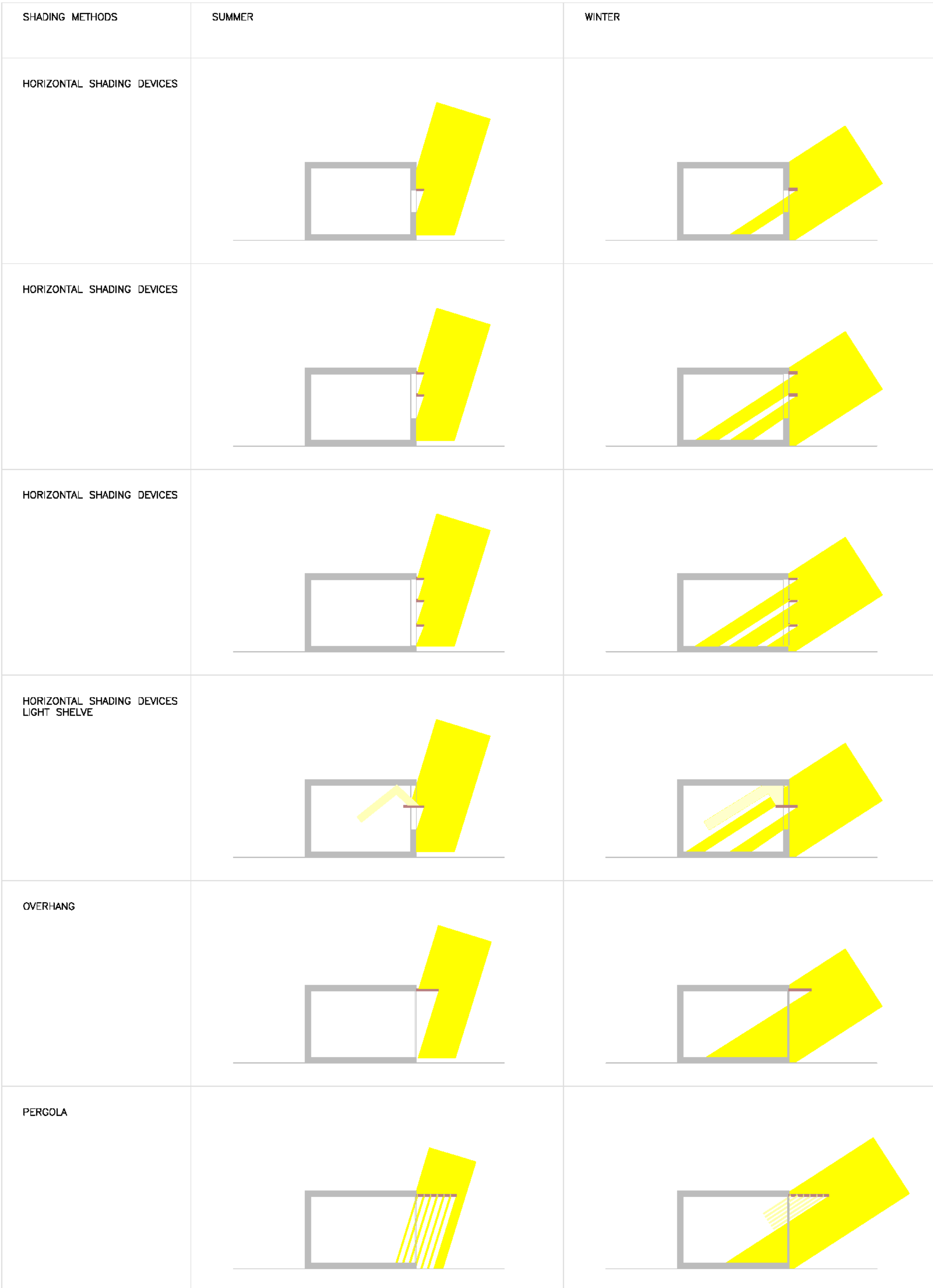


Figure 3.12 Shading methods

Figure 3.13 Shading methods

Natural Ventilation

Throughout history, people in Cyprus have relied upon natural ventilation for comfort in buildings during the summer. Buildings with massive elements are traditionally common, night-only ventilation has generally been used. Night-sky radiation and evaporative cooling have also been used in conjunction with night ventilation. Traditional architecture has provided both lightweight and massive construction.

Good ventilation is the key to a comfortable and healthy home. The house can be cooled while opening and closing doors and windows remove hot, stale air. This natural effect is sufficient to keep a home comfortable. At other times, the forces of air pressure and gravity are not enough to circulate air though a building, so some type of mechanical device is needed to provide adequate ventilation. Fans and ventilators are an effective way to enhance air circulation. This forced ventilation can supplement or even replace air conditioning. Through careful selection and proper sizing, fans and ventilators can increase comfort levels and reduce energy costs. A small amount of ventilation is necessary to control odours, moisture, and pollutants (radon, formaldehyde, etc.). For older homes, natural infiltration through cracks in the house envelope is sufficient for such ventilation needs [0.6-1.0 air changes per hour (ach)]. But infiltration may not be sufficient to ventilate contemporary, tightly constructed homes adequately, and mechanical ventilators with air-to-air heat (or enthalpy) exchangers may be required (BPA, 1984).

The size and location of the inlet and outlet areas determine the rate of airflow. The greatest volume of airflow occurs when the inlet and outlet areas are equal. The velocity of local airflow is greater when there is an imbalance between inlet and outlet areas. Larger outlets create a faster airflow near the smaller inlets, and larger inlets create a faster airflow near the smaller outlets. Therefore, the airflow in certain areas of a building can be changed by simply opening and closing windows. For example, opening all windows on the leeward side of a building, and closing all the windows on the windward side except in one room maximizes airflow in that room.

One other type of natural ventilation arises in rooms with only one window. Here, minimal ventilation is created as some air enters the room at one time and a few seconds later some air exits because of the fluctuating static pressure of the wind. This pattern creates minimal ventilation (Warren, 1984).

When designing a building for natural ventilation, there are several guidelines to follow:

- The building is designed to respond to winds from any direction.
- Inlets and outlets for airflow in each room are provided.
- Inlets and outlets are located so air will flow through parts of the room most likely to be occupied, such as the sitting area in a den, and stagnant areas are avoided.
- Windows and doors are used that open fully.

- Vents and windows are accessible and easy to use.
- Blocking windows with exterior objects such as shrubs and fences are avoided, but do not eliminate shading. Tall trees allow air to enter while providing shade.
- Vent openings are concentrated in spaces most likely to require cooling.
- Overhangs, porches, and eaves are used to protect windows and vents from rain. This extends the amount of time that natural ventilation can be used.
- Vent openings are tightly sealed in winter or when using an air conditioner.

Minimal ventilation and infiltration rates are required in buildings as well as in attic spaces to prevent condensation and wood rot (ASHRAE, 1984).

Figure 3.14 Cross ventilation

Cross Ventilation: Steady wind-driven ventilation, i.e., cross ventilation, is usually the strongest mechanism and is produced when a prevailing wind direction creates distinct positive and negative (suction) pressures at the inlet and outlet. Unsteady pressure differences also may be created by wind, such as changing pressure patterns over a windward wall with two widely spaced windows on the same wall. The fluctuating wind directions, typical in suburban or other rough terrain, create unsteady pressure fluctuations that can generate significant ventilation (Goulding et al., 1993).

Stack Effect: The stack effect arises because the density of air decreases with temperature. Thus airflow can be induced in a thermal chimney external to the building, which, in turn, can ventilate a house. Designers in climates like Cyprus should commonly practise stack effect ventilation (Baer, 1983) (Crowther, 1980). During the summer in Cyprus, daytime ventilation is impossible and the building gradually heats up during the day. At night the cool air flushes through the building. The night-time wind speeds are usually low, thus the wind effect is enhanced through the stack effect by placing high outlets (e.g. operable skylights) and low inlets.

The stack must terminate above the roof peak so that the stack top is always under suction compared to the lower inlet level. Otherwise, a wind coming from the opposite direction can introduce the hot stack air into the room (Schubert et al. 1983). One must also be careful designing Trombe walls for stack ventilators in the summer. Unless the Trombe wall is insulated at the interior side in the summer and is vented at a high point at the top, unwanted heating may result. In general, the stack effect is weak. The cross-ventilation airflow from a 2.7-m/s wind can overcome that from an 2.4-m stack at 43°C. But during windless nights that typify the summer conditions in many parts of Cyprus, fan-forced ventilation may be the only alternative for providing airflow (Chandra et al. 1983).

Solar Chimneys: Solar chimneys use the sun to warm up the internal surface of the chimney. Buoyancy forces due to temperature difference help induce an upward flow along the plate. The chimney width should be close to the boundary layer width in order to avoid potential backward flow (Bouchair, 1988).

Wind Towers: Wind towers draw upon the force of the wind and generate air movement within the building. There are various systems based on this principle. The wind-scoop inlets of the tower that are oriented toward the windward side capture the wind and drive the air down the chimney. The air exists though a leeward opening of the building (Bahadori, 1988) (Karakjatsanis et al. 1986). The airflow is enhanced by cold night air. Alternatively, the chimney cap is designed to create a low-pressure region at the top of the tower, and the resultant drop in air pressure causes air to flow up the chimney. A windward opening should be associated with the system for air inlet. The anabatic process benefits from the buoyancy of the warm inside air. Both these principals may be combined in a single tower providing both admittance and exhaust of air. A self-contained system is thus created.

Atria: Atria are usually used for inducing stack ventilation especially in larger buildings. Open atria and courtyards usually get hot during the daytime but can cool down at night (Eureka Laboratories, 1982)

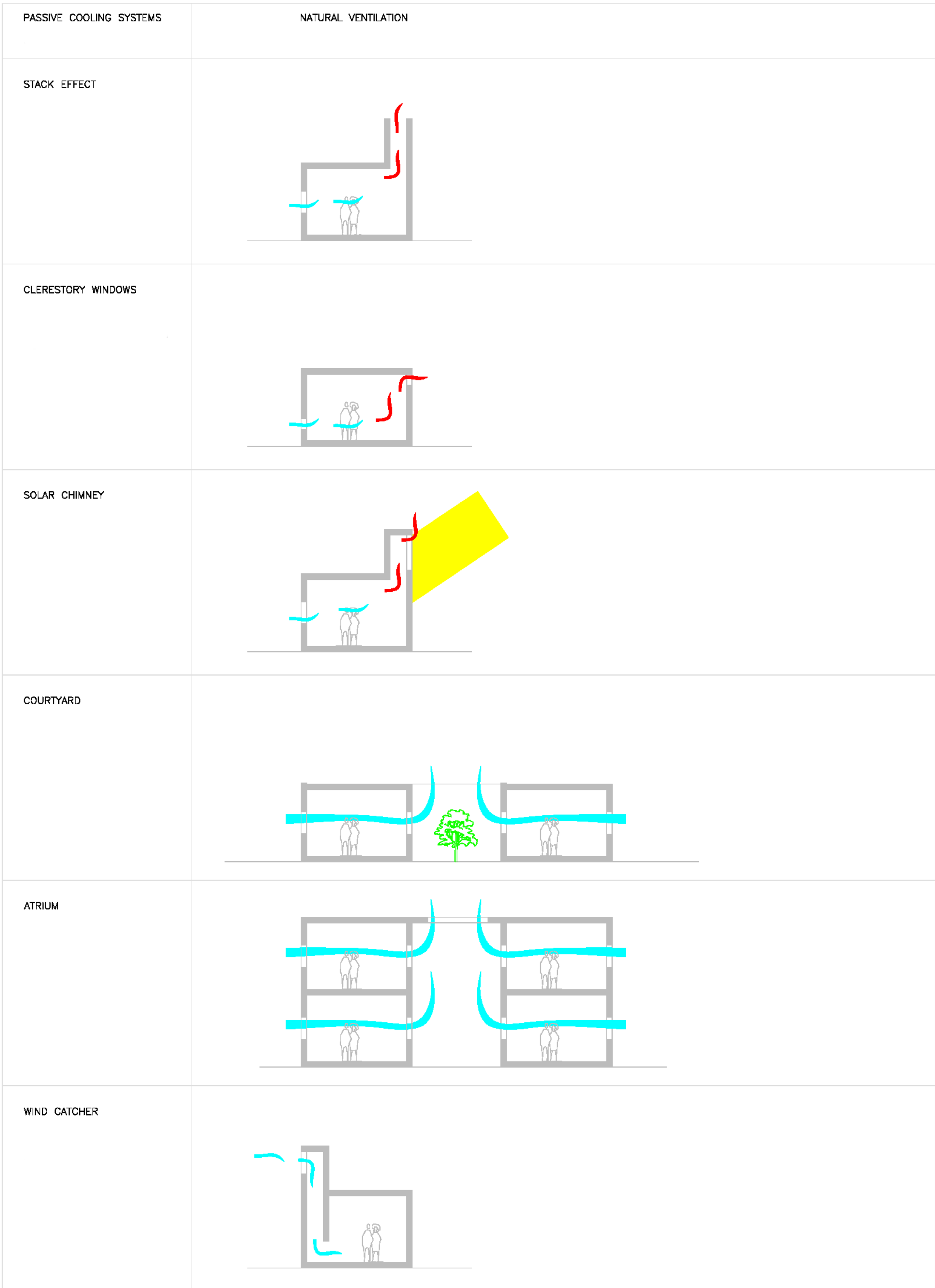


Figure 3.15 Natural ventilation methods

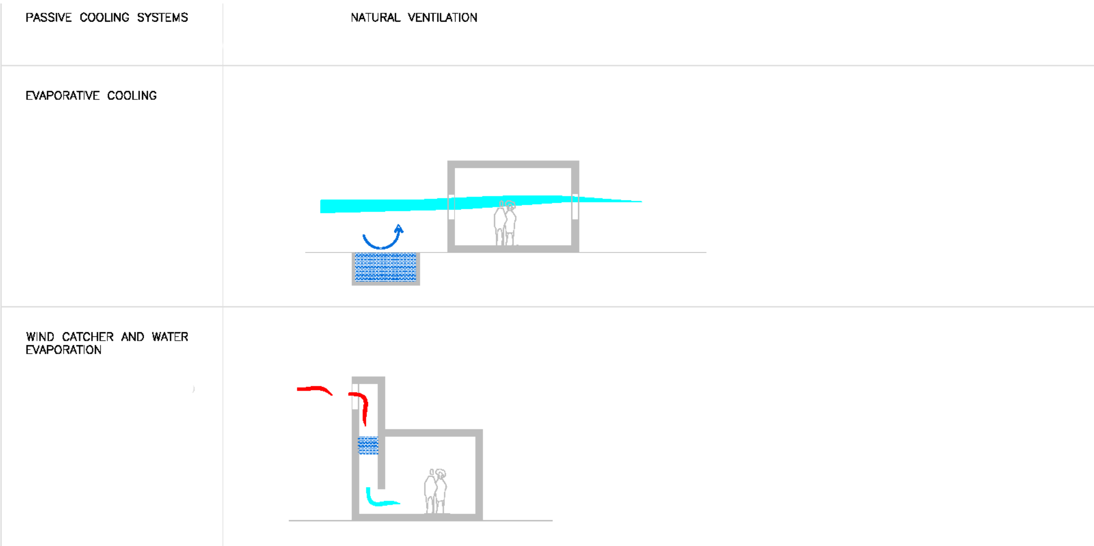


Figure 3.16 Natural ventilation methods

Vegetation: Vegetation in the form of trees, shrubs, creepers and ground-covers can be effectively used to improve the micro-climate of a building in the following ways: providing shade-deciduous trees is excellent for shade in summer while they allow sun through during the cold months. Evergreens can be effectively used for shading the building or outdoor areas from the low-lying sun if the right type is selected. Deciduous creepers growing over a pergola or on a wall surface can provide shade for the summer and permit sun to penetrate when needed in winter.

Vegetation affects airflow that can be accelerated or directed through buildings by correct and careful planning as long as the behaviour of the flow is predictable. Great care must be taken, however, to ensure that the free flow of cooling breezes is not obstructed.

Shelter-dense planting of evergreen vegetation (preferably in two or three rows) can be used to form windbreaks, provide protection against wind-blown windbreaks, provide protection against wind-blown dust and sand, as screens (both visual and for privacy), as well as for reducing glare.

As vegetation is grown easily and often densely in the mountains-the main problem can be to restrict its growth or find trees and shrubs which will not obstruct the flow of breezes. In the plains, on the other hand, vegetation is extremely sparse and as it's beneficial influence on the micro-environment can be enormous.

Although a relatively wide range of vegetation thrives in Cyprus and almost anything can grow where there is sufficient water, it must be noted that there is not one uniform climate (mountainous area, coastal area and plains area). Each area has its own peculiarities and differs from one-another. As plants can cost a great deal to grow in arid areas,

it may be advantageous if they can have a dual function; in other words a tree or shrub grown for shade could be selected from those which bear edible fruit.

Depending on the kind of trees, vegetation filters sunlight and protects against direct radiation. A complete obstruction to solar irradiation provides cool areas of shade in summer, while deciduous trees allow solar penetration in winter for solar gain.

Different types of barriers may provide various effects of wind control depending on their height, density and spacing in relation to the building. Directing air movement towards the building and reduction of wind speed should carefully be considered according to seasonal wind conditions at a given location. Wind protection and natural ventilation require the proper placement and screening of vegetation barriers in order to give the desired degree of control in specific situations.

Figure 3.17 Natural ventilation methods -Vegetation

Night Ventilation

Night and evening ventilation of massive buildings is a common strategy in Cyprus where daytime temperatures are too high for ventilation. Whether permanent use of night only ventilation is desirable depends on the building type and climate as well as whether a backup mechanical system is used. Givoni (1976) conducted side-by-side tests of several building models of different constructions and colour and insulation levels. He found that permanent ventilation was better for white models. In other words, well-designed buildings (light coloured, insulated, shaded windows) will maintain daytime indoor temperatures lower than the outdoors, and thus it is pointless to ventilate them during the day. This situation is likely to be true for both arid and humid climates.

Effect of Air Movement on Thermal Sensation

It is known that as velocity rises, the air temperature in which one feels comfortable also rises. However, there is an upper limit to air velocity above which air movement itself causes annoyance. According to Olgyay (1963) and Szokolay (1980), the effect of air movement alone for temperatures around comfort are as follows:

Up to 0.25 m/s : unnoticed

0.25-0.50 m/s : pleasant

0.50-1.00 m/s : awareness of air movement

1.00-1.50 m/s : draughty

Above 1.50 m/s : annoyingly draughty

Therefore, an upper limit of 1.50 m/s can be set above which discomfort begins because of a draughty environment. The 1.5m/s value is acceptable for high temperatures (but less than skin temperature) because an experience of draught can be pleasant if one is too hot. Actually air velocities of 2 m/s have been found acceptable by some authors (Archard et al. 1987)

Ceiling Fans

Ceiling fans are another means to circulate air. They replace or supplement air conditioning in a home. Some ceiling fans are reversible. Blades turn clockwise in summer to create a down-draft, and counter clockwise in the winter to circulate the heated air collected at the ceiling down towards the floor. Others come with light fixtures. Ceiling fans can also add a decorative touch to a home. With ceiling fans, the thermostat setting can be raised up to 5°C from the thermal comfort level (Clearinghouse) (depending on the occupants' preference). Separate fans should be placed in all frequently used rooms. They should be located over areas that are likely to be occupied, such as over the seating area or over the bed in a bedroom. Ceiling fans work best when the blades

are 210cm to 280cm above the floor and 25 to 30cm below the ceiling. Placing fans so that the blades are closer than 20cm to the ceiling can decrease the efficiency by 40 percent. Fans also require at least 45cm of clearance between the blade tips and walls. They should never be hung where excessive moisture could damage the wiring or warp wooden blades. These fans are best for rooms that tend to build up heat, such as sun-rooms or rooms with a wood-stove.

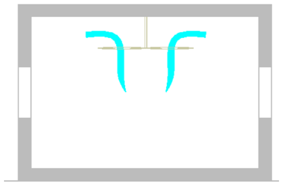


Figure 3.18 Ceiling fans

Occupant Behaviour in Passive Solar Houses

The interaction of occupants with passive solar systems can be very positive. Solar houses, built in the 1970's in USA, were custom-designed by people who were sensitive to energy and environmental concerns. In many cases, the owner, designer, and builder were the same person. For instance, the majority of passive solar homes surveyed in studies by the U.S. Department of Energy (DOE) were custom-built, with many owners actively involved in design, construction and financing.

These designer-occupants typically had the motivation to pay careful attention to the operation of the energy-related features of their home, such as movable insulation. They were also willing to sacrifice a certain amount of comfort for energy-savings, by turning thermostats to very low set-points, for example, or by opening a window and wearing light clothing when the direct gain space overheated.

When scientists (Socolow, 1978) surveyed energy use patterns of low and moderate income households they found that occupant behaviour had a greater impact on home energy consumption than greatly improved thermal integrity and sun-tempering, and that occupants with "energy-saving" behaviour would use less energy even in a conventional house than occupants with "energy-wasting" behaviour living in a house designed for maximum energy-efficiency (International Energy Agency, 2009).

Studies conducted on monitored gas consumption in nine identical three-bedroom town-houses (Gaskill, 1981) found that one home consumed twice as much as another over a two-year period, due entirely to different occupant behaviours. The connection was confirmed when a change of owner caused one town-house to shift from the most energy-intensive to the least.

The studies (Solar Energy Research Institute, 1983) (Solar Energy Research Institute, 1984) (NAHB Research Foundation, 1984) and experience with occupant behaviour suggest three major reasons for wasteful or counterproductive energy behaviour:

1. Lack of understanding on the part of the occupants as to how the passive solar system is supposed to operate.

2. Improper passive solar or building design.

3. Disinclination of the occupant to be actively involved the building's passive solar system or energy performance.

Even if a passive solar system is simple and requires relatively little occupant involvement, descriptive materials such as fact-sheets or booklets, explaining how the house has been designed to save energy, will be useful to the occupants and encourage their participation. Where the system is more complicated, occupant education becomes even more critical. Occupants consider same manual operations, such as opening or closing a door between a sunspace and a living room to control great distribution, inconvenient. Therefore, the importance of reasonably faithful operation should be emphasised. The information need not be lengthy. The essential information can probably be contained in just a few pages or a few appropriate sketches. Studies show that the reasons people buy passive solar homes, and the reasons they like them, have a great deal to do with factors other than energy savings. (International Energy Agency, 2009).

Conclusion

What one can conclude from the passive solar design discussed in this chapter is that, for the climate of Cyprus or any given climate, there are a number of choices of solar techniques from which to select, each with advantages and disadvantages that must be weighed in terms of the local climate, construction practice and competing fuel costs.

Taking into account the advantages and disadvantages of the passive solar system it is concluded that the best systems which can be used for Cyprus are the following:

- Direct Gain

- Thermal Insulation

- Thermal Storage (Interior Mass): The simplest heat storage approach is to construct the building of massive structural materials insulated on the exterior, to couple the mass of the indoor space.

- Solar Control: By use of: orientation, shading devices.

- Natural Ventilation: By use of: cross ventilation, stack effect, night ventilation and ceiling fans

However, preliminary recommendations regarding the above-mentioned passive solar means may not be adequate to state that a particular building will not be overheated in the summer or under-heated in winter. A proper assessment regarding such decisions cannot be made without calculations that involve a suitable prediction method of indoor air temperatures and numerical external and internal design data.

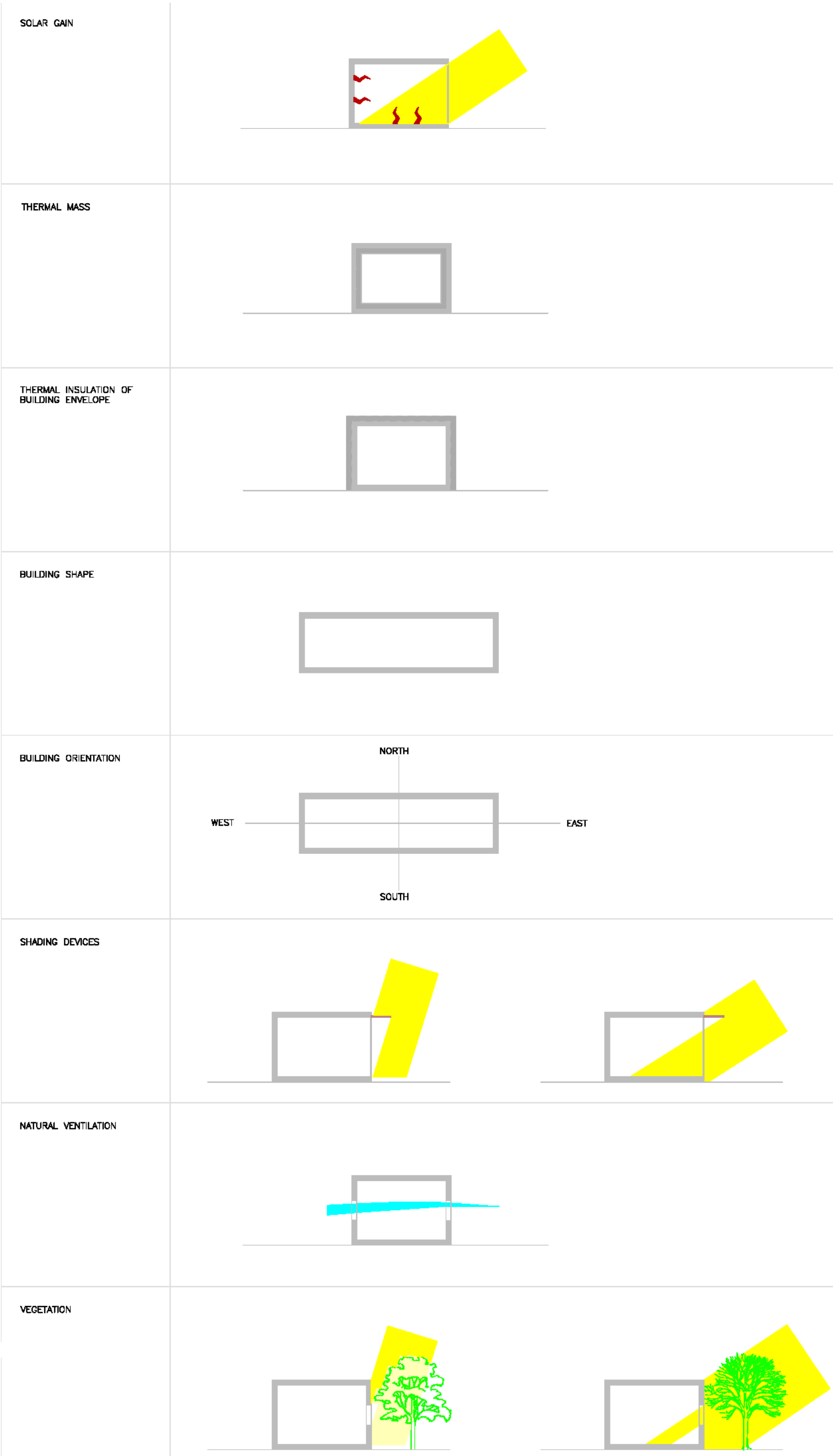


Figure 3.19 Bioclimatic Strategies

TRADITIONAL vs CONTEMPORARY BUILDINGS

Introduction

Man has always strived to build his dwellings in order to attain optimum conditions of comfort. In all cases, man has found some fairly good and some excellent solutions. Architects, critics, and consumers have recently been questioning the way in which professionals in Cyprus have been planning and building, particularly in connection with how buildings perform as energy-consuming entities.

Approximately since 7000BC, until the mid 20th century AD, construction methods have varied only slightly (Papacharalmbous, 1968) (Sinos, 1976) (Hatzichali, 1967) (Demakopoulos, 1981). The same building material such as wooden beams, straw, clay mixtures and stones were used in approximate methods. The buildings are designed and constructed to fully exploit advantages offered by local climatic conditions. The construction of buildings was made economical by using materials found in the area like stone, wood, reeds, earth and terracotta. Structural solutions were simple and effective. For example, the available length of trees used as roof rafters established the dimensions of room widths.

Neolithic Age

The most ancient Cypriot community known to archaeologists is Khirokitia (Brun, 1977). It was found that many of these Neolithic structures exhibited insulated walls that be considered as passive solar techniques.

The basic architectural unit was a structure with a circular ground plan, the exterior diameter of which varies between 2.3 and 9.2m and the interior diameter between 1.4 and 4.8m. (Dikaios, 1953) (Gjerstad, 1934). Walls were found to be made out of stones set on one or two courses and bonded with mud mortar. Mud brick or rammed earth walls were made of stones embedded in rammed earth. Walls were even built in two concentric rings, the outer one of stones, and the inner one of rammed earth or mud bricks, the latter sometimes resting on a stone substructure. A whitish earth plaster covers the internal and external faces of the wall. Flat stones, set on edge around the base of the wall would sometimes protect it from erosion by rainwater.

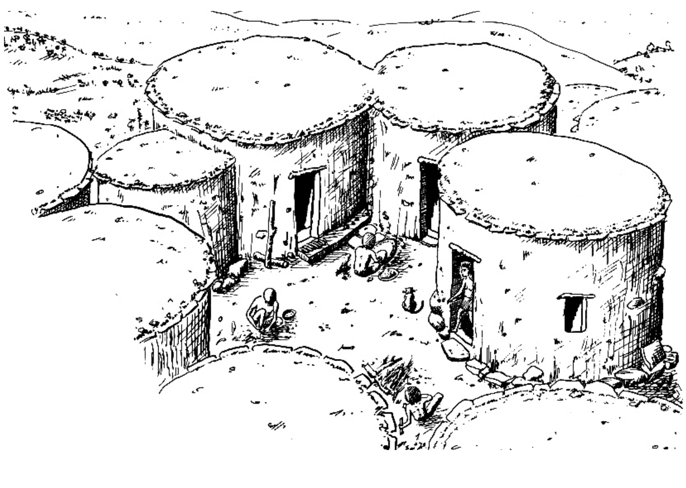


Figure 4.1 Khirokitia village (Le Brun, 1997)

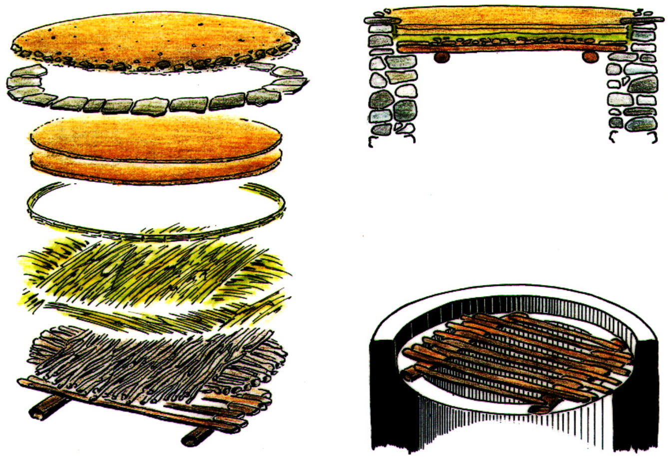


Figure 4.2 roof reconstruction (Todd, 1998)

Each of these units, with their diverse internal arrangements, was part of a larger domestic space: the house. Its ideal form, as can be reconstructed from the excavations at Khirokitia, may be defined as a compound of several of these circular units around an un-roofed space, a kind of small inner "courtyard". The total domestic space was large enough to shelter a family, place of various spatially defined daily activities.

Traditional Buildings

In Mediterranean and hot climatic regions where sunshine in winter is desirable and cooling and ventilation in the summer necessary, the solarium (illiakos) and the courtyard are indispensable solar features of houses and unique elements of Cypriot traditional architecture. Their arrangement evolved naturally from the climatic conditions, the needs of the family and the social structure of the community (Serghides, 1990). When the courtyard faces south it acts as a sunspace that receives desired solar radiation in winter. The extent of the solarium cover allows the rays of the winter sun to penetrate allowing solar radiation to be utilised in winter.

Town Type Housing

In towns, because of the limited space available, houses were built within fortress walls in order to be protected against invaders and in order to meet the different needs of people, mainly merchants and craftsmen as opposed to people living in villages who were mainly farmers and developed a different type of house. Usually these houses where small, two-storey houses, with small back yards. Between the neighbouring houses, no space was left so their walls were attached together.

Their shape was rectangular, usually divided into two rooms but their orientation was according to the direction of the public road. The yard was placed at the back of the house, enclosed by adobe walls with the only access to it through the house. Later, when additional rooms such as kitchen, storeroom etc. were necessary, these were built in the back yard (Economou et al. 1985).

On the upper floor, there was usually either a balcony or a kiosk that faced the public road. The access to the upper floor was through an indoor stoned stair placed in the biggest ground floor room.

The materials used for the construction of these houses were mainly adobe blocks. Some of them were constructed from limestone with mud and lime mortar as connecting material. Wealthy people preferred stone built houses. For the south wall, shading was achieved through the solarium (iliakos). Its roof shaded the mid-day sun-rays whereas its side-walls shaded the morning and afternoon sun-rays.

Roofs were usually pitched and constructed from timber trusses on which the planking was covered with clay tiles or schist stones. Instead of planks, reeds were sometimes used covered with mud. The slope of the roof ranges from 25-40 degrees with the lower angles in the plains and the higher in the mountain regions.

Floors separating storeys where constructed from timber. The lower floor consists of hard-packed soil and was sometimes covered with slates. Doors and windows were always made from timber and external shutters were used for the windows.

1. Entrance door

2. Main ground floor

3. Backyard

4. Auxiliary rooms

5. Bedrooms

6. Balcony or Kiosk

7. Stairwell

8. Terrace formed by the roof of auxiliary rooms

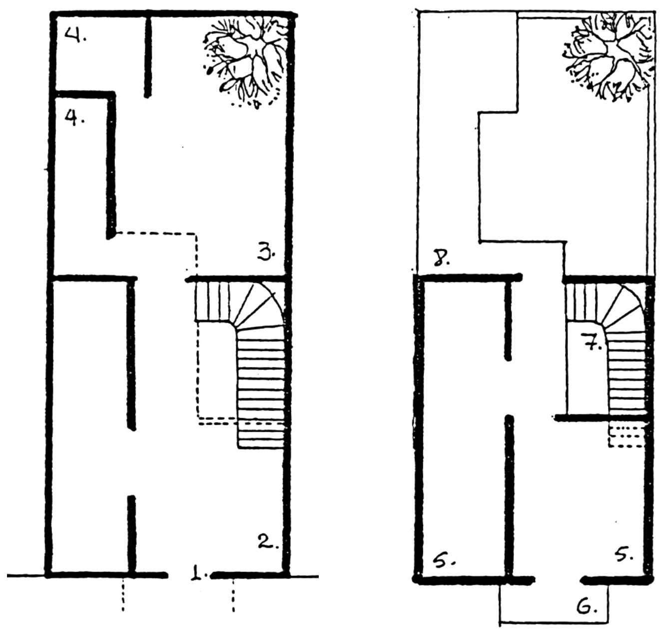


Figure 4.3 Typical type of house built in towns. Ground floor and top floor (Economou et al.. 1985)

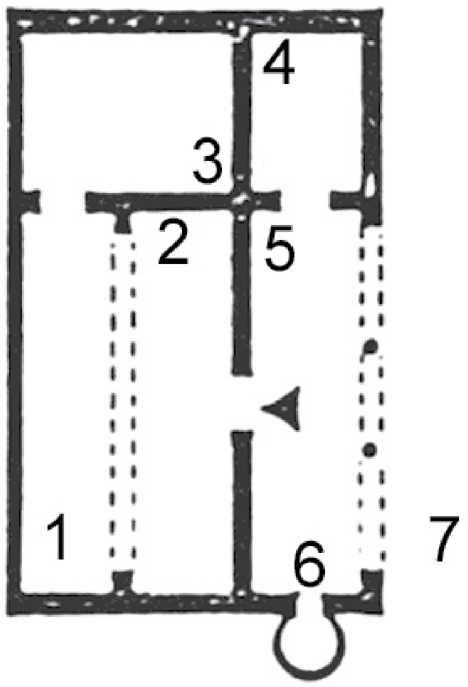
Rural Type Housing

Most rural type houses had only one floor, but two storey houses were sometimes constructed. Houses were usually smaller in size than the town type, with limited openings, while the development of villages was compact for defence purposes and lack of available space. In most cases there was a courtyard in front of the house, and where there was not, the flat roofs were used for open-space activities. Stairs leading to the upper floor were either external, made from stone, or internal, made from timber.

Tracing the evolution of indigenous Cypriot architecture, an archetypal form of a single, long, rectangular room building (Makrinari) is revealed as the simplest basic shelter in Cyprus (Economou et al. 1985). It is generally south oriented with its long axis along the East-West direction. Eventually, the division of this double space room (Dhichoron), the addition of other inner rooms (Sospiton) and a covered veranda (Iliakos) were placed.

Later this type of house was developed into a multi-room house, by adding extra rooms to the east or west of the 'Makrinari' plus the courtyard. These additions sometimes maintained the rectangular shape of the house but at times it led to the L-shape (Sinou, 1976). Despite these changes to the general layout of the house, the south facing 'iliakos' facing the courtyard did not change.

The courtyard is an arrangement that evolved naturally from climatic conditions, the needs of the family and the social structure of the community. It generally creates a micro-climate that moderates the climate surrounding the building. Planted mostly with deciduous vegetation like grapevines, fig trees etc., it offers shade in the summer and admits sun in the winter. It also creates windy sides that are most valuable when one seeks the breeze in the summer and calm corners in the winter. Arched arcades on the perimeter are indispensable to shield the overhead mid-day sun (Fernandes et al. 1988).



1. *Makrinari*
2. *Dhichoron*
3. *Inner room*
4. *Inner room*
5. *Iliakos*
6. *Traditional earth oven.*
7. *Courtyard.*

Figure 4.4 "Iliakos" (solarium) (Sinou, 1976)

External and internal walls were made from stone, usually schist, without any connecting material. They were plastered inside with sand and lime mortar while the external side was left un-plastered and whitewashed in most cases. Roofs were usually flat. The construction method was as follows: first a framework of timber beams was constructed and then covered with schist, clay tiles or reeds. Over these, seaweed or other plants were set and finally the construction was completed with a thick layer of soil that provided insulation. In some rural areas where timber did not exist at all, roofs were stone

vaulted constructions. In some cases the vault was visible externally and in others is covered with soil. Floors between storeys were made from timber and ground floors were usually paved.

All the openings were placed towards the south facing wall in order to provide natural light and heat. The construction of these openings was made entirely with wood. Small openings (arseres) were also used in every house. These were placed on the upper part of the walls. In summer, they allowed lighter hot air to go out of the house and be replaced by cooler air from outside, while in winter, thyme (small dense bushes) was used to close these openings and provided thermal insulation.

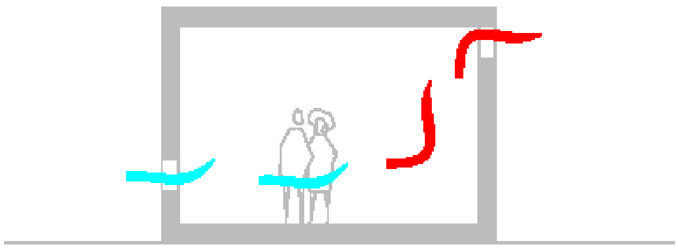


Figure 4.5 "arseres"

Thermal Performance

Taking into account the general characteristics of the dry climate and the requirements it imposes on building characteristics and thermal performance of traditional buildings, it may be concluded that traditional buildings in Cyprus meet the requirements imposed by the climate and that these buildings are good enough thermally to perform well under the prevailing weather conditions. It should also be mentioned that one of the main factors, which make the thermal performance to these buildings successful, is the integral interaction between their design and the occupancy patterns.

Architectural Design

The inward looking design of traditional buildings is a successful feature from the point of view of thermal performance. The open courtyard works as a thermal regulator in many ways. Its high walls exclude the sun and shade a large area of the inner building surfaces. The fruit trees and grass found in the courtyard, contribute to keeping the air cool and providing shade accompanied by visual and psychological relief. Rooms and terraces surrounding the courtyard are normally incorporated in units, each consisting of two or three rooms and a central terrace.

External windows may be found on one or two sides of the building, depending on its position in the planning area. Such windows are limited in number, small in size and positioned high up on the wall in order to reduce the amount of heat admitted into the building as well as to reduce ground glare during summer. As the width of each window is almost equal to the thickness of the wall, such windows also function as vertical louvres and prevent most of the direct solar radiation from penetrating into buildings.

Construction Materials and Methods

Materials used for the construction of traditional buildings in Cyprus are stone, sun-dried mud-brick and timber. The only rendering material is mud plaster. This material deteriorates quickly despite sometimes being mixed with long pieces of hay to improve its structural and thermal properties. They are also used to erect massive ground floor constructions, effective in smoothing large diurnal temperature variations which occur during the summer. Such construction has a high thermal capacity and it therefore absorbs much of the solar heat during the day, thereby extending the time before the temperature of the internal surface shows any appreciable increase.

In winter, the massive construction of traditional buildings may also be heated by solar radiation, which dominates for a long time during the day. Heat emitted inwards during the night may then be considered as one of the desirable properties of the structure.

Occupancy Patterns

The occupancy patterns of these buildings vary with changes in both daily and seasonal weather conditions. Daily changes in occupancy patterns are mostly limited to the summer time, when during the hot hours of the day, people seek protection from the heat and retreat to the ground floor, away from hot regions near the roof. In the evening they expand their activities outdoors and make the courtyard their living space. During the night they move upstairs and use the rooms of the first floor and/or the flat roof for sitting and sleeping.

In winter, the ground floor is rarely used unless it includes the kitchen and other services. The first floor is usually the only space used during day and night because it is of a relatively lighter construction, easy to heat by solar radiation caught through the windows, which are greater in number and larger in size than those available on the ground floor.

Contemporary Buildings

Before the Cypriot independence in 1960, specialised building tradesmen constructed dwellings. In particular, the existence of travelling building teams was very important because as they moved from place to place, they learned a lot from local architecture and influenced the method of construction and building types in other regions. Furthermore, local people began to travel abroad and influence construction by bringing prototypes back from many countries.

The Turkish Invasion of Cyprus in 1974 brought a deep economic crisis and 200 thousand refugees, which were uprooted from their land in north Cyprus by Turkish troops. Architects were forced to consider architecture as a social science rather than a fine art. This was a period when it was necessary to search for an appropriate architecture that could deal with social problems.

Government housing was designed to be constructed quickly and to relieve the burden

of refugees living in tents. Refugees immediately decorated the front of their homes with plants and vegetation, turning them into sorrowful new homes. Although quickly and cheaply constructed, these homes satisfied basic needs with a shaded porch area and a solar heater for hot water.

The housing problem in Southern Cyprus was immediately dealt with by the government's initiative and action, beginning with the reconstruction of destroyed areas to alleviate the housing shortage in the cities. As a result, the housing problem passed into the hands of private businessmen, first in Nicosia and then in other cities. In fact, because of the absence of other investments, the building industry began to play a determining role in shaping the Cypriot economy. The new government took measures towards regulating the urban space, in the aim of stabilising the regime. Many image-driven public building projects began and several laws were passed making construction policies less strict, allowing higher buildings and increasing the floor area ratio. As a result, private building construction boomed.

The main planning problems are basically derived from the fact that the vast majority of developments in Cyprus are based on small individual plots, the so called regular plots, of an average size of 550m^2. Traditionally, the development system in Cyprus was encouraging the parcellation of very small building plots . As a consequence, the building quarters in Cyprus are very small, the percentage of road surfaces to other urban surfaces is quite high (25-30%), urban settlements are very extended and the population densities relatively low. In 2003 some incentives where employed in the respective Local Plans. According to these, a bigger building plot ratio by 10-20% is allowed in cases of integrated and organized development in plots 4 to 6 times bigger than the regular plot sizes of the respective area, or by 5% in cases the development plot has a surface bigger than 5000m^2.

Another serious planning problem seems to be the neglect of climatic and environmental conditions. Given the constraint of the small building plots mentioned above, designers have limited chances to exploit the opportunities of any site's orientation, topography, local winds, vegetation etc. Therefore it is rather difficult to spot a few environmentally functional building envelopes. Even the limited number of organised developments that allow more design freedom are usually fixed to the surrounding grid system and the norms of smaller projects.

Consequently although the first substantial reductions of some plot ratios (above 200%) were enforced in the main towns, many new development zones were created in order to set the ground for new structures. As a result, private building construction especially focused on tourism and housing industry boomed during this period. A series of reforms were introduced to the new constitution that specified that the protection of the physical and cultural environment is an obligation of the state. All the reforms reflected the necessity for an adequate planning mechanism in the field of housing and environmental and land use planning. However, the Cyprus government has not yet established implementation procedures and reserves (4 out of 33 Municipalities) the right to act on any problem by highly centralising the decision-making process of all these fields.

Cyprus employs a lot of housing systems. Within the context of the housing policy for

the refugees, the government of Cyprus has introduced various schemes and programs like the "Low Cost Government Housing Scheme" that provides houses, free of charge, to low-income families. Until 2001, more than 12.500 families (or 5,6% of the total number of households) were benefited from this scheme in 71 housing estates. In addition to that the government provides the "Self-help Housing Programmes on Government Land" (where 9.000 families, or 4,1% of the total number of households, have already been housed in 321 estates of this type), the "Self-help Housing Programmes on Private Land" and the "Purchase of a House /Apartment Scheme".

In the private sector, development and construction companies offer, in the free market, various types of housing units and mainly apartment or terrace houses. This type of development satisfies nearly 30% of the total demand. A substantial number of families however, choose to build their own detached or semi-detached house, on an individual plot of land, which has an average surface of 520 m2. It is worth mentioning that in 2001, 68,2% of the total number of households in Cyprus had their own private housing units.

Social and aesthetic aspects are usually forgotten because they are not directly related to primary human needs but rather to the comfort and quality needs of the people. Designers and contractors prefer the straight-forward solutions, that satisfy the basic human needs. On the other hand, most of the buyers and tenants prefer simpler and cheaper housing units, than buildings or complexes that accommodate "social spaces". This is because social places will have an increase on the cost of the building or rent.

Unfortunately traditional construction methods, techniques, materials etc. have been ignored for the sake of fast development and fast profits (by the building industry) due to the absence of a necessary statutory framework that would guarantee the building quality, but also due to poor awareness of consumers' rights. Due to the age of buildings many problems are observed. The main problem is their maintenance. The maintenance and administrative matters of apartment buildings is entrusted by residents. In cases where maintenance costs are higher, the agreement of all residents is required in practice, which often encounters difficulties even in simple administrative matters and often proves to be ineffective in the case of serious repairs or maintenance work on the building.

Today, the socio-political environment is again changing at a quick pace, with Cyprus becoming an official member of the European Union in 2004; this has brought the protection of the environment to the forefront of its concerns, making it a political priority. In Europe, processes and procedures have been set and laws have been adopted that make the protection of the environment a fundamental objective of society. With the resulting institutional framework that has now also been adopted by Cyprus as a complete member of European Union (EU), Cyprus has included in its legislation more than 300 Directives and Regulations and a range of related action plans that concern the subject of protection of the environment. The harmonisation of national and EU legislation has resulted in a large number of laws and regulations (Republic of Cyprus 2006) for the following subjects:

- Law for the assessment of environmental impacts from certain projects.

- Eco-label, environmental management and audit (EMAS), protection and management of nature.
- Noise management.
- Management of waste.

Various governmental and non-governmental organisations (NGOs) have established policies for environmental and sustainable issues according either to EU directives or by laws of professional organisations. Of course, we have other cases as well, where NGOs have established their priorities in relevant issues, and are working towards planning the strategy that will facilitate the promotion and realisation of those priorities.

Current Housing Habits

In an attempt to evaluate some of the current housing habits in Cyprus, two questionnaires were compiled (Lapithis, 2002). From the outcome of both questionnaires, it transpired that most dwellings in Cyprus are constructed with little or no insulation and this is the most likely cause for the high percentage of summer and winter discomfort as well as noise complaints. Most other complaints stated (e.g. poor natural lighting) are the result of unsuccessful bioclimatic orientated design. All this suggests the need for better, more bioclimatic appropriate constructions, with adequate insulation and proper orientation with respect to the sun.

- A high percentage (69%) of the survey participants experienced bothersome noises from the outside, probably as a result of poorly insulated wall surfaces and single glazing which not only allow heat to enter and exit freely, but also allow noise to penetrate with little difficulty.
- A high percentage of the participants frequently felt cold in the winter (80%) and an even greater number felt warm in the summer (87%).
- There were complains about bothersome cold surfaces (70%).
- Another problem area, which can be minimised by proper passive design, is the need for artificial lighting (64%).
- Participants experienced drafts from windows and doors (86%). An element of ventilation that can be exploited in a passive system, if it is designed properly.
- There is a need for a more widespread use of double-glazing windows in order to minimise moisture condensation on windows (65%), and for a better thermal and noise control.
- An interesting fact deduced from the survey was that the overwhelming majority of Cypriots feel safe in and around their house (91%), which makes it easier for a passive solar designer to arrange for ventilation systems requiring frequent openings; espe-

cially for night time ventilation.

- Another advantage the passive solar designer will have in Cyprus is the fact that the Cypriots seem to appreciate the use of shutters (87%), which have been used in traditional architecture.

- Of the 13% of participants who did not find shutters an acceptable means of controlling indoor temperatures, most attributed this to the fact that the shutters do not work properly. This implies the need for shutters to be placed in front of windows and to be more appropriately planned.

- The majority of dwellings have no insulation (66%).

- Of the houses that do have some insulation (34%), it mostly is in the form of double-glazed windows and reflective silver coatings (a waterproofing material, which is misunderstood to act as a thermal insulator) rather than in structural constructions, which implies that most insulation in the surveyed houses was more or less treated as an afterthought.

Method of Construction and Effect on the Built Environment

Contemporary life and the building industry in Cyprus are greatly affected by the proliferation of apartment blocks in the large urban centres. The apartment house became the symbol of the final stage of urbanisation. And since urbanisation is the ideal way of living for the contemporary Cypriot, the apartment model is adopted everywhere, even in small single houses at the most underdeveloped areas of the country.

Sites (individual plots) in Cyprus are usually small and private, with an average size of 500-600m^2. The time and the method of construction as well as the use of the building are mainly the decision of the site's owner. The two main systems of urban development are the continuous and the free system. The continuous system refers to an orderly, gridded pattern of plot sizes and boundaries whereas the free system refers to a more erratic separation of fields into individual plots.

Three categories of construction financing have been developed.

1. A contractor undertakes the construction of the building.

2. The owner of the property decides to play the role of the contractor-entrepreneur and undertakes the responsibility of constructing and financing the project. He/she usually sells or rents most of the apartments, keeping one or two for him/her.

3. The owner of the property builds one housing unit for the present needs of his/her family, allowing for the possibility of constructing additional apartments in the future to cover the needs of the growing family or merely for investment reasons.

The results of this practice in the city are the following:

- Lack of planned connection between housing areas and other areas of the city (educational, commercial, etc.).
- Mixed housing areas with industrial or other areas, dangerous for public health.
- Very limited green and open spaces within the housing areas.
- Bad relation between street width and building height.
- Different housing types even in the same street, such as large apartment blocks adjacent to low houses (Aravantinos, 1984).
- Unplanned and often unhealthy interaction between the built and natural environment.

In an analysis of the built environment of the city area, (Sariyiannis et al. 1977) it was concluded that the negative points of the housing environment are not due to the lack of adequate housing units, but due to the use of a continuous construction system. This results in the lack of open spaces and a lack of quality of the immediate environment around the houses with the result of little natural light and ventilation, no solar access etc.

Thermal Performance

The architectural design of contemporary buildings (post 1970) in Cyprus are profoundly influenced by western architecture and there exists a tendency to recreate an international architectural style without considering the advantages of traditional architecture and the distinctive climatic conditions and social life. Furthermore, despite the fact that there are some fine examples of contemporary buildings based on correct design principles and a better understanding of the local climatic conditions, the great majority of contemporary buildings are erected without consideration of the climatic conditions and their influence on comfort and the well being of occupants. This is mainly due to lack of knowledge about the thermal performance of contemporary constructional materials and methods, and consequently the shortage of building regulations which govern this aspect of the art of building.

However, most contemporary buildings in Cyprus have appropriately designed functional plans. These buildings are also frame-built, flat-roofed and enclosed with thin non-load bearing largely glazed block work walls. Their plans may sometimes be flexible but not so much as to permit occupancy patterns similar to those available in traditional buildings.

Architectural Design

The extensive use of reinforced concrete frame in the erection of contemporary buildings has made it possible for structural and non-structural building elements to be well

defined. Accordingly, external walls have almost become non-structural elements dominated by vast glazed windows. The curtain wall, which is a non-supporting skin made up from window mullions and in-fill panels and cantilevered from the frame structure, has also become easier to construct.

The above-mentioned innovations and advancement in building design and technology have made any form of building possible to create with materials such as glass, metal and building panels of every kind, that characterise the new architecture. These features of contemporary buildings have also created many problems in Mediterranean countries for they are not suited for the climatic conditions.

Despite the design flexibility possible in the frame-built, non-load bearing wall buildings, the plan development has been neither parallel to advances in new technologies nor based on the traditional plan form.

Construction Materials and Constructional Methods

In general, the typical housing construction system in Cyprus is based on the conventional construction system, quite common in this part of the Mediterranean Sea. The system comprises the use of reinforced concrete for the load bearing part of the building, which is completed by masonry walls. Prefabrication systems have rarely been used in the past, mainly by the Government for the construction of some low cost refugee estates in the late 70's.

Reinforced concrete, from foundations to the roof, is used for the vast majority of the housing constructions. It has to be mentioned however that preliminary regulations regarding the calculation of seismic loads were issued in the late 80's and these detailed construction regulations were adopted in the beginning of the 90's. Thus all the buildings built before that, may sometime in the future, face possible seismic failure.

The typical filling of multi-story family houses comprises of brick walls (20 or 25 cm for the outer walls and 10 cm for the inner walls) that are plastered with 2-2,5 cm on either side. The finishing surface is usually covered by sprits (cement based top coat plaster for exterior use) or paint.

In most cases, the whole of the load bearing structure, including the foundations, consists of a reinforced concrete frame. This method of design is a must for the buildings in Cyprus due to the seismic excitations that the structures undergo during their life. The surface of the concrete is either "fair face" or "typical" depending on functional or aesthetic criteria.

There is a variety of foundation types according to the type and size of the structure. The most popular are the separate foundations with connecting beams and the general (whole) foundation. The outer skin of a structure, is usually created by reinforced concrete parts (for the load bearing structure) and a single layer of bricks, (200mm), both coated with three layers of plaster (20-25mm) and a finishing layer of paint or sprits. The roofs are usually flat concrete slabs, which are covered with light concrete or screed of

50-100mm for thermal insulation and on top with an asphalt layer of 2-5 mm, for humidity insulation. The final touch is given with reflective paints.

During the past 10-20 years, some multi-story family houses appeared to form a different top finish with a complete or partial pitched roof. It is believed that this is used not so much for insulation reasons, but rather for promotional reasons since it gives a touch of a more domestic or more humane housing. As far as windows are concerned, the vast majority of them are single glazed (4-5 mm) with aluminium frames whereas a considerable proportion of multi-story family houses, especially after 1980, used double glazed windows.

Occupancy Patterns

Residential buildings are usually occupied continuously or intermittently. It is however normal to find more than 90% of occupants at home by 3pm during the summer. As the structure of contemporary buildings is with a short time-lag of the order of 2 to 3 hours and as the maximum amount of solar radiation falling on buildings in summer takes place at midday and the maximum outdoor shade air temperature appears at about 2pm, the maximum temperature of the external surface appears at about 1pm. Accordingly, the maximum temperature of the internal surface appears about 3 or 4pm. Heat emission into buildings therefore takes place during the resting time of the occupants, when the outdoor shade air temperature is still high and such heat cannot be removed by ventilation.

Moveable fans are widely used but with little effect on improving the indoor conditions because the draught of external air is already of a high temperature and the distribution of air movement is non-homogenous. The overall result is physiological and psychological dissatisfaction (Kolokotroni, 1985).

As many contemporary residential buildings are comprised of apartments normally designed with a specific function for each space, occupants are obliged to carry out their activities in the specified zones regardless of the daily and seasonal change in weather conditions. Alternative spaces, which can be used to avoid the overheating effects at certain times of the day, seldom exist.

Comparison Analysis: Traditional vs Contemporary

Kolokotroni (Kolokotroni, 1985) had summarised different aspects of both traditional and contemporary buildings (table 4.7). The similar aspects of these buildings may therefore be compared with each other and an understanding of the thermal performance of both traditional and contemporary buildings in relation to the climate shall be clarified.

From the thermal performance point of view, traditional buildings are much better than inappropriately designed contemporary buildings. This means that thermal performance is not the only criterion by which the use or abandonment of traditional and contemporary buildings may be evaluated.

The progress in design and technology which may have been misused because of lack of knowledge and experience, inappropriately designed contemporary buildings, has also stimulated awareness of many short-comings in the design of traditional buildings which do not match the requirements of contemporary urban life. Progress in design and technology has also provided many means by which the shortcomings of contemporary buildings may be overcome, with new buildings incorporating design advantages of both traditional and contemporary buildings may be created.

Aspect	**Traditional Buildings**	**Contemporary Buildings**
Architectural Design	-Inward looking with courtyard -Square or rectangular plan -One or two floors -Covered terraces -A body of water and fountain -Clerestory windows -Flat, domed and vaulted roofs	-Outward looking -Free plan form -Multi-storey blocks -Small balconies -Vast glazed windows -Flat or pitched roofs
Constructional materials and methods	-Local materials found on the site of the building or brought from a nearby area -Simple constructions -Load-bearing walls	-Materials are mostly imported or locally made with poor qualities -Frame structures -Simple constructions -No insulation -Non-load bearing walls
Occupancy patterns	-Changed in residential buildings. The ground floor is used in summer days and the first floor in summer nights and in winter	-Unchanged in residential buildings because of the design restrictions of contemporary buildings
Planning	-Compact planning with courtyard -Shortages in services	-In-compact planning. No courtyard -Zoning problems
Thermal performance	-Satisfactory during both summer and winter and at all times.	-Unsatisfactory during the times of overheating and under heating.
Non-thermal comfort problems	-Necessity of annual maintenance -Shortages in services -Shortages in natural -Lighting and ventilation -Inaccessibility in case of emergency	-Weathering problems -No adequate building regulations -High influence of the building contractors -Acoustic problems
Demand	-Decreasing because of being not suitable for contemporary urban life	-Increasing because of social and economic changes and contemporary life

Table 4.7 Comparison analysis: Traditional versus Contemporary (Kolokotroni, 1985)

Weathering problems of contemporary buildings are closely related to the two main aspects of the climate of Cyprus i.e. the high values of solar radiation during summer

and the subsequent wide diurnal and annual range of outdoor shade air temperature. The influence of the two above-mentioned aspects on contemporary buildings is much greater than that on traditional buildings mainly because traditional building materials belonged to the local environment, while those of contemporary buildings are mostly imported or of poor qualities. Weathering problems of traditional buildings are almost limited to the mud rendering of the external surfaces and the exposed internal surfaces. Such problems are also caused by rainfall, which make such rendering weak, soluble, and in need of almost annual replacement.

The necessity of annual maintenance does, however, make traditional materials unsuitable for use in the new urban towns and cities. It is therefore inevitable for contemporary materials be used, which means that weathering problems affecting these materials should be pointed out and avoided. The high surface temperature of the building structure during summer days increases the rate of deterioration of the low night air temperature, making many materials brittle and subject to cracking under stress. Deterioration of building cladding materials caused by solar radiation means that such deterioration is in turn transferred to the fabric. To prevent such deterioration from taking place, adequate thermal insulation and movement joints are required.

EXPERIMENTAL SOLAR HOUSE

Introduction

The Experimental Solar House was constructed in order to put theories developed in research into practice. The principles of passive solar construction are complex in theory but remarkably simple in application. A passive solar house may be constructed anywhere in the world provided there is enough knowledge about climatic and site conditions. None of the decisions made for the Experimental Solar House could be justified without the rigorous study that has been presented in earlier chapters.

In commencing a project such as the Experimental Solar House, the first and foremost priority was to design a home that would match the average specification of a new residential construction in Cyprus. To build a database of these specifications, information was collected on various construction statistics (Karouzis, 1980). Based upon these findings the size and space usage requirements of the experimental house was determined. Following that, the findings of questionnaires on current comfort issues of Cypriot homes were analysed and attempted to be improved by applying appropriate passive solar systems.

The research on thermal comfort concluded that, for Cyprus, an average 19.5-29°C is an acceptable temperature and an average of 20-75% is acceptable range of relative humidity. It is concluded that it is impossible to accurately specify final temperatures and RH for the average person, because of psychological, physiological and practical factors. It is concluded that the passive systems that are most suited for Cyprus are: Direct Gain, external insulation on walls (0.29W/m²K) and roof (0.28W/m²K), low emissivity double-glazed argon-filled, interior thermal storage constructed from bricks and concrete, 5% north wall openings are sufficient for cross ventilation during summer nights, optimum of south wall openings 18%, permanent external shading devices, vegetation, use of natural ventilation and ceiling fans.

With regard to the size and spatial layout of the ESH, it was decided early on to investigate the present situation in Cyprus in order to find ways of improving the thermal performance of the new housing currently being constructed. Therefore the model is based on the typical four person Cypriot family house. Should the size, or the spatial layout, be substantially altered, further research is needed to investigate the effect of changes on the internal environment.

In this research, a detached house was used because from the point of view of a thermal environment it represents the worst arrangement. A detached house has greater heat losses in the winter and heat gains in summer as opposed to terrace houses or blocks of flats, because all the external envelope of a detached house is exposed to external conditions. Therefore, if care is taken not to obstruct the sun in winter and the ventilation in summer, terrace houses of blocks of flats should perform thermally better than detached houses. However, further investigation is needed to quantify this improvement.

A plot of 620m² was acquired for the purposes of this case study. This plot is in the inland region of the island, in the suburbs of Nicosia, Kato Lakatamia. In Cyprus, it is customary for most people to buy the plot of land in which they will build their home. Usually the plot is between 550 and 650m². Sometimes, two individuals will buy one plot of land

and share it between them by building two semi-attached houses. Only a percentage of the plot can be built according to local legislation. Over the last 20 years, the average size of a house ranges between 150 and 250m² varying on the owners' income. An average family with one or two children will usually build a house of approximately 200 m². Sometimes two individuals will buy one plot of land and share it between them by building two semi-detached houses.

The users' behavioural patterns were based on the way Cypriot people usually occupy their homes during the winter and summer. However, it is important that the occupants operate the house efficiently; otherwise there is no point in designing it according to bioclimatic rules. For example, a large glazed area on the south wall will be wasted if the window shutters are closed during sunny days in winter, while a movable shading device will serve no purpose if it is not in place during daytime summer, as previously discussed. The heat capacity of the external walls will not perform efficiently if the windows are open during hot summer days and closed during summer nights. It is certain that bad management of a bioclimatic designed house affects its thermal performance for the worst.

The experience of living in the Experimental Solar House after it has been completed is one that could have been predicted. The house has succeeded in providing well-lit spaces during all the hours of natural sunlight as well as even and comfortable temperatures during the day and night.

Design Considerations

From the onset of the design process, the author established that the ESH should occupy the northern part of the plot so that the southern side faces the garden. By arranging the south side to be looking at the garden, it is ensured that no potential construction shall obscure the house's exposure to the sun. It was decided from the early stages of the design, that the house will have an area of close to 200-250m2 so as to approximate the average size of a contemporary house in Cyprus. The final area of the house is 223m². The construction costs should not exceed 140,000 Euro, taken into account that this is the construction cost of a typical house in 1998 (Staurou 1998). Similarly, the house shall have all the most common components of a two level Cypriot house:

- Top level: bedrooms, an open plan master bedroom with a shower and toilet plus a Jacuzzi (optional), one toilet with a bath

- Lower level – open plan: kitchen space, dining space, living space, sitting space or TV space, one toilet situated under the circular staircase.

At the initial stages of designing the ESH, several passive solar systems were considered. The systems finally chosen were the ones most appropriate for the overheating and under heating periods of the location (See chapter passive solar systems). In general however, the interior design is more flexible to accommodate the needs and preferences of the current owners.

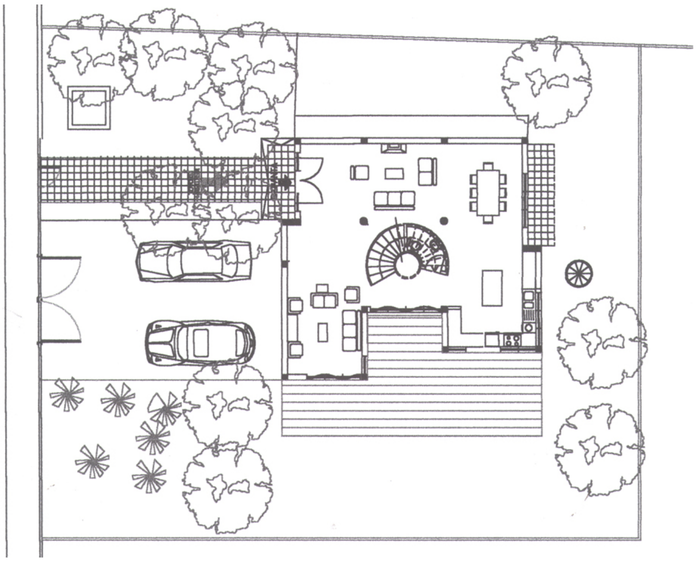


Figure 5.2 site plan of the Experimental Solar House in a single plot of land (Typical plot of land for Cyprus)

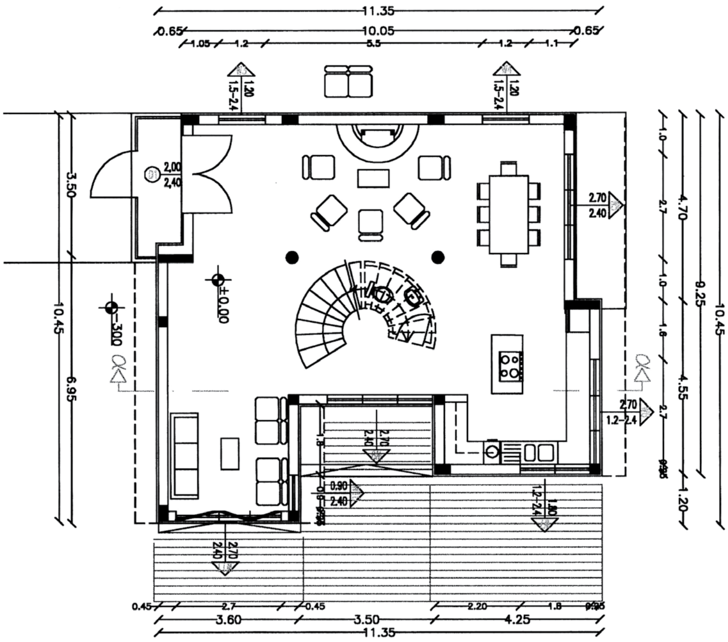


Figure 5.3 ground floor plan of the Experimental Solar House

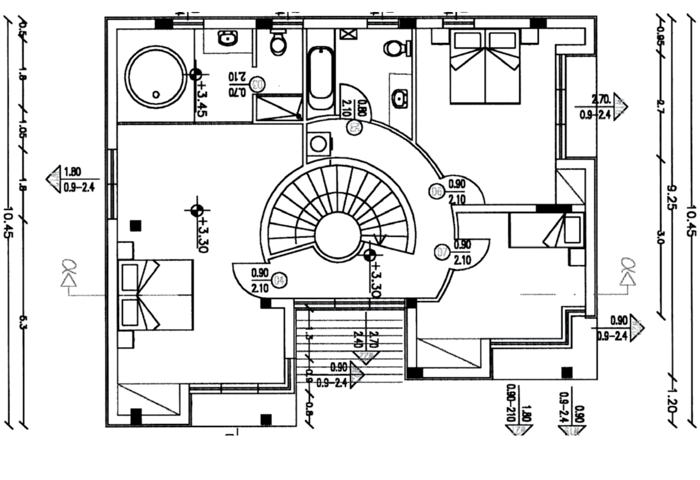


Figure 5.4 upper floor plan of the Experimental Solar House

Each different variation was calculated by the computer software Energy 10 looking at the optimum interior comfort temperatures without the use of auxiliary heating in the winter. However, it became apparent that in order to better regulate the interior temperatures, a fireplace had to be installed as auxiliary heating to compensate the few cold rainy winter days

The footprints of the house begin with the least arbitrary volumetric shape, the cubic. As discussed in chapter vernacular vs contemporary buildings, and passive solar systems, the cube was the main form of building in Cyprus, as well as flat roofs in the inland region. The decision was made so as to combine the traditional way of building with modern life. Major volumes jutting in and out of the frame are kept to a minimum. Additionally, it has empirically been seen that keeping wall surfaces to a minimum results to fewer walls requiring insulation, thereby keeping thermal losses and costs down.

The ground floor creates an open plan arrangement, which is given some order by the concrete circular staircase located roughly in the centre of the floor. The staircase acts not only as an aesthetic pivot but also as a solid body to hold thermal mass. The kitchen is located on the south-eastern side of the plan allowing the kitchen to be the recipient of a healthy amount of natural sunlight on a daily basis. The kitchen will receive morning sunlight both in the winter and in the summer, and it will be well lit for the rest of the day, up until a few hours before sundown. The kitchen windows are ideally located for parents to keep an eye on playing children while cooking or snacking on the kitchen island.

The dining area is located on the north-eastern side of the ground floor space, immediately behind the kitchen space. The dining table will receive morning sun thereby enriching the breakfast experience whereas the ambiance of evening dinning will be accompanied by electrical lighting. The dining area is adjacent to the north wall, which has minimum openings so as to reduce heat losses and to prevent temperature fluctuations. This feature of a north wall in a passive solar house may seem limiting at first, but with careful consideration, a large number of functions can be located adjacent to the almost window-less north wall. In addition to dining, the north wall can host the fireplace and the television area. It can also be ideal for hanging large artwork.

The south-western corner of the house that receives plenty of sunlight, particularly in the afternoon is ideal for living room space. It provides full view of the garden and direct accesses to the kitchen. Adjacent to the living room is the toilet, located compactly inside the staircase. The door of the toilet is not visible neither from the living room space nor the kitchen.

On the upper floor there are two bedrooms accommodating a two children family. One of the rooms can also be converted into an office space or a guest room. One of the two rooms has windows facing east and south and the other has just the east windows. In addition to the two bedrooms, there is the master bedroom which includes a separate space within the master bedroom for a shower, a toilet and a Jacuzzi. The master bedroom has windows facing south and west. All upper floor windows are recessed so as to protect them from summer overheating. The cavities created underneath the windows are used for closet space.

There is an additional toilet and bath on the upper floor to accommodate the other two bedrooms. In the case of a two-member family, the additional toilet can be converted into a laundry room. The advantage of the laundry space located on the upper floor in the corridor is that no great distance need be travelled with dirty laundry originating from the bedrooms and the showers.

Typical concrete foundations are used for the anti earthquake calculations (required by the Cyprus governmental laws). The construction was decided to be done as the typical Cypriot contemporary home which consists of a concrete frame, concrete for floors and roof and for the walls brick work plastered on the interior and exterior of the walls (discussed previously). The roof is constructed by concrete and the beams of the house are reversed so that they will not affect the interior of the design of the top floor. Wood beams and metallic sheets cover the 600mm reversed beam construction, which shows on the roof. In this way, an extra 600mm air cavity is being formed assuring a better insulation. On top it is covered by a 100mm expanded polystyrene and concrete was used for forming the water canals of the roof.

The water sewage treatment installation is placed on the northern side. This does not affect the typical plumbing installation of the house, since it is an external device instead of the typical sewage tanks that are used in Cyprus. The concept is to construct the house as all the typical contemporary houses are constructed, with the only difference being the passive solar features.

The electrical installation is also done by the typical contemporary methods. The only difference is the photovoltaic tracking system, which follows the movement of the sun. The system is just added on the main electrical meter and is grid connected to the electricity authority. In this way, the sun produces electricity without affecting the typical electrical installation. The system consists of 12 panels of 85W each, thus producing 1020 KW/h. The photovoltaic array could have been on the roof but the architect has decided to place it on the ground, to produce a sculptural effect on the landscaping of the garden.

The ground level has an open plan in order to facilitate a constant indoor temperature and natural ventilation. It was also a personal decision on the architect's behalf. It was also considered that if the ground floor was divided by walls, it was ensured that all the rooms would have south openings for the sun penetration and small north openings for the north summer breezes. Since it is an open plan, when the east and west, or north and south openings are open cross ventilation occurs.

A circular staircase was located centrally in order to provide a mass surface area of the staircase wall facing south. The staircase wall is used as a thermal mass storage which radiates heat in the winter evenings. Entering winter sun entering is dispersed to the rest of the house.

On top of the staircase are the clerestory windows, which create a stack effect for ventilating the interior space in the summer, and allowing the winter sun in. This is one of the traditional ways of cooling and ventilating the building in the summer

Another design decision geared towards trapping winter sunlight is the large south window surface on the first and second floor lobby. Since the staircase is used as internal thermal mass the south window openings ensures that enough winter sun is entering the house and the staircase without the problems of the direct gain systems discussed previously.

An additional measure towards blocking the summer sun from entering the house and the large south openings is the pergola attached to the southern wall. There is a separate pergola on each floor. The pergola is a simple, wooden construction, covered with straw mat. The pergola also serves as a much-needed shading device for the veranda. In the summer the straw mat is placed on the pergola and in the winter it is removed. The traditional way is to have vine trees on the pergola, which was used as a natural summer shading device and in the winter when the leaves fall, the winter sun penetrates. This is being considered and vines have been planted. But they require 2-3 years to fully grow, so in the meantime the straw mat is being used.

In order to address the problem of summer overheating, several applications of passive solar systems were considered and it was decided to employ the following. The architect chose to recess the second floor bedroom windows on the southeast and south walls so as to prevent summer sun from entering, but at the same time allowing winter warmth to enter. They are used as permanent shading devices so as to avoid movable shading devices. The recessed windows create a hollow space from the inside of the room, above and below the window frame, which can be converted into storage space.

Roof fans are used to assure that no overheating occurred in the extreme overheated periods. It is actually one of the best active ventilation systems, since the indoor comfort temperatures are not high.

The feature that enhances all the overheating preventions is the second floor overhang. The overhang, apart from the aesthetic addition it offers the building, provides more space for the recess of the windows and also protects the first floor windows from excessive summer sun and winter rainfall.

The front door is located on the west side of the house, the side on the street. Other than the entrance, there are no major openings on this wall and even fewer on the north side. The front door, which is also recessed, is protected from draughts by placing a glass surface and door to cover the recess, which also acts as a buffer space and a front entrance vestibule. This front entrance system has yet another advantage: during a warm winter sunset, the front wooden door can be kept open while the glass door is kept closed so that warmth from the sun is allowed to enter and heat up the interior acting as a conservatory by using the principles of isolated or direct gain. The front double wooden door has 5cm expanded polystyrene acting as thermal insulation in order to ensure that the temperatures in the buffer space do not influence the internal house temperatures. In the summer, to ensure no overheating in the buffer space, the glass door is kept always open.

According to principles of passive solar construction, the north wall needs to have the fewest interruptions possible. The more openings the north wall has, the more oppor-

tunity is provided for valuable heat to escape during the winter and enter during the summer (direct solar gain due to the summer sun orientation). The west wall, which also happens to be the front façade of the house, has fewer openings than the east, so as to protect the house from unwanted sun at summer sunset. The east facade requires more windows since it is important to allow the morning winter sun to enter and heat the house that has cooled overnight, while in the summer deciduous trees are used to avoid excess summer sun.

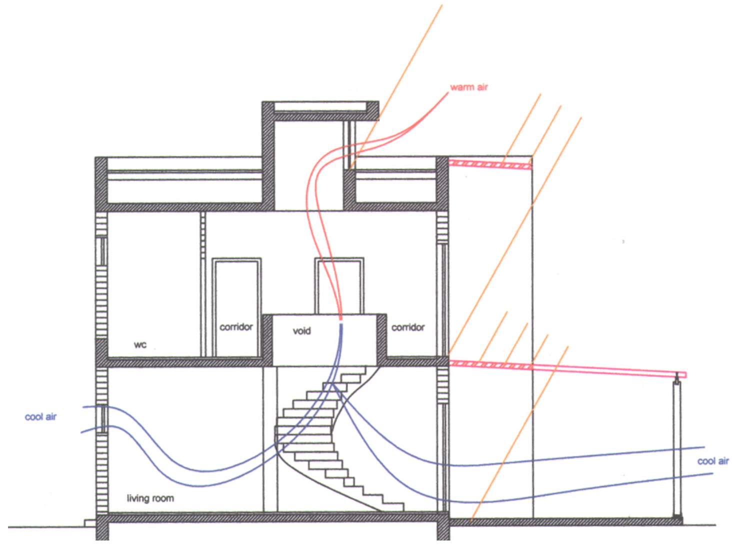


Figure 5.5 summer design considerations (north-south section through the staircase).

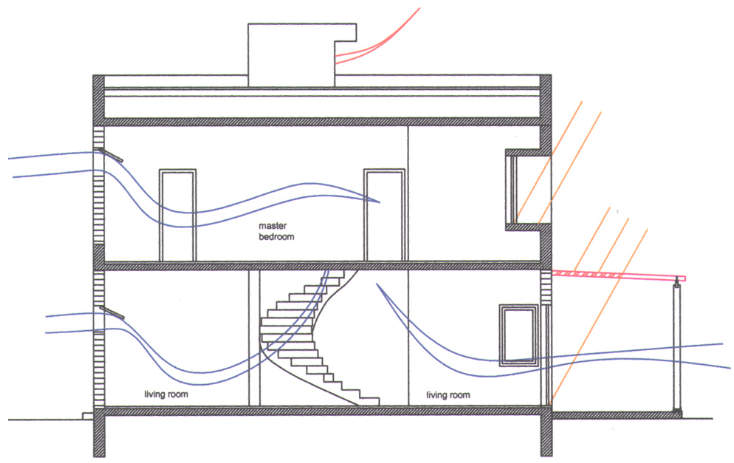


Figure 5.6 summer design considerations (north-south section through the staircase)

The bedrooms on the top floor were also heated by the fireplace through the stack effect. When the fireplace was used the doors of the bedrooms were kept open. Warm air rises through the open staircase and enters the bedrooms, since there was no other escape route. Naturally, the inside temperatures of the bedrooms were slightly lower (1-2°C) than the living room.

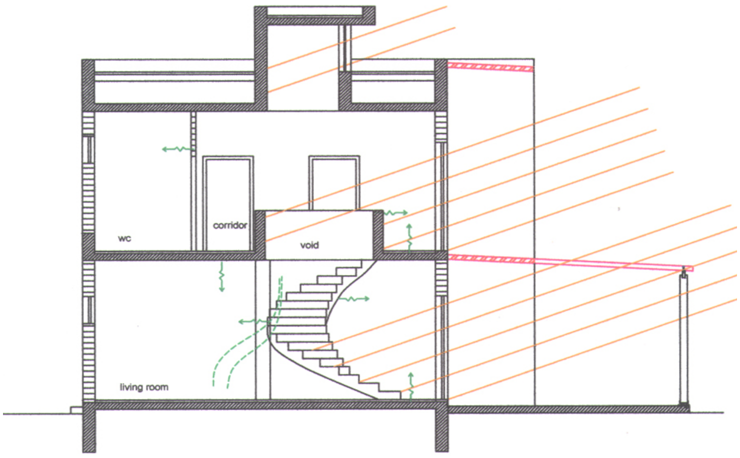


Figure 5.7 winter design considerations (north-south section through the master bedroom)

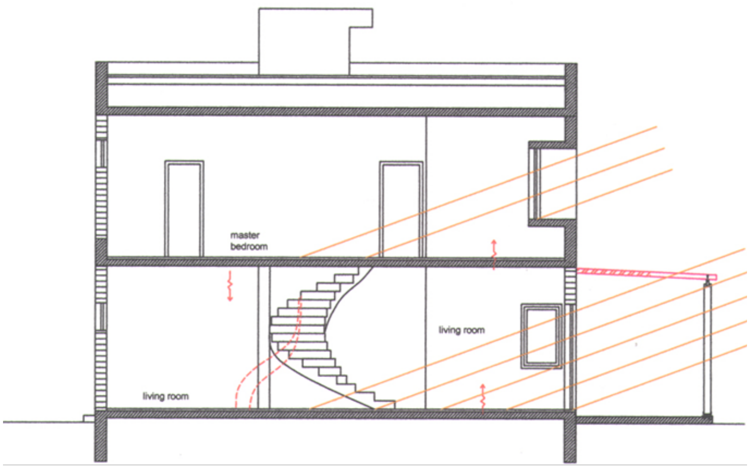


Figure 5.8 winter design considerations (north-south section through the master bedroom)

Plumbing and Sewage

When providing for the plumbing facilities for the solar house, it is imperative that certain basic requirements for habitation are met. The water in the solar boiler must always be hot when the hot water tap is switched on. One must not consume cold water while waiting for the hot water to arrive at the tap. The boiler will also provide the hot water for the washing machines. It must have enough hot water capacity to accommodate the washing machines and the showers, and it must be ensured that the water will not run out even if the entire tub is filled with water. In order for this to be achieved a 300-litre capacity boiler with four solar panels has been installed, ensuring hot water in the winter.

There are two tanks of 2,000 litres capacity on the side of the house, one filled with clean water from the municipality and the other filled water collected from an on-site water well of non-potable water. The clean water will be used for the sinks and bathrooms and the non-potable water will be used to flush the lavatories. There is an additional tank of 18,000 litres capacity, which is placed underground and filled with rainwater. This tank will be used as backup for when the smaller grey water tank runs dry.

The water from the sewage will drain to the water-treatment tank and then it will be stored in a separate tank. This water will then be used to water the plants in the yard that are not fruit bearing or edible. The fruit-bearing trees will be watered using the water well. After 15 years a pond of approximate area 100m2 was installed and was filled with rainwater.

Additional measures for water conservation were the installations of the servo-set flushing mechanism in the lavatories. This compact device used in place of the regular flusher, allows the inhabitant to choose to flush much water or less water, according to need.

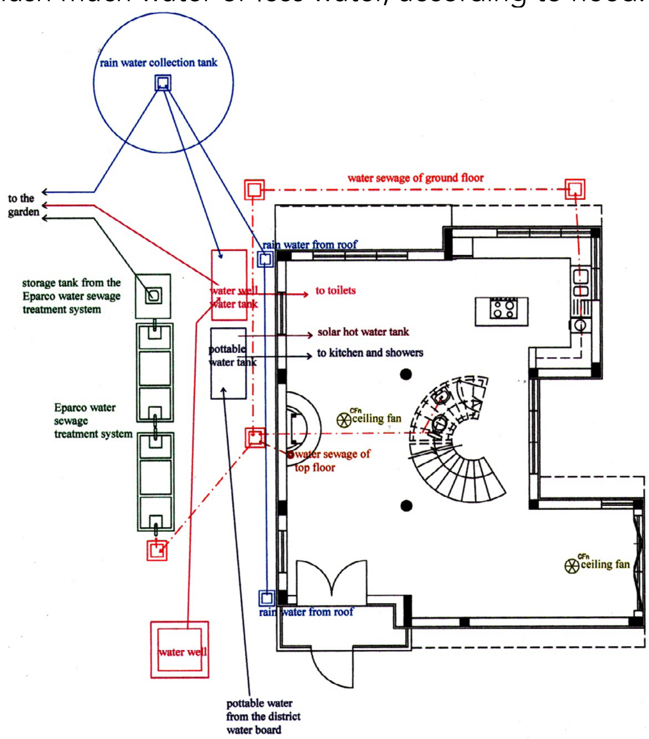


Figure 5.9 Plumbing and sewage

Wall and Roof Construction Consideration Methods

Wall construction: For the construction of the ESH, 13 methods of wall construction were taken under consideration (Table 5.1, 5.2, 5.3). Upon further examination of all viable options for an efficient passive wall, the following solutions for a masonry-insulated wall were considered.

For plastering the external wall where polystyrene was placed a special plastering was being used. This called Adesilex FIS 13 specially used for insulation panels. The reason for this is that typical plastering used on brickwork (mixture of water, cement and sand) will form cracks when placed on polystyrene. Adesilex FIS 13 is a whitish paste with a synthetic resin base in water dispersion, selected aggregates, and special additives. When mixed with cement, it forms a highly adhesive, highly thixotropic, easily workable mortar that can be applied vertically without sagging and with no slippage, even when used for large-size insulating panels. Portland 325 cement is added in proportion of 1 to 1 by weight. An even first layer of the Adesilex FIS 13 mix thick enough to incorporate fibreglass mesh reinforcement (approx. 1-2 mm) is spread. After the first layer is dry, a second layer is applied until the mesh is completely covered and the surface is ready to receive its final covering.

For a passive building, the walls need thermal mass in order to retain heat. With that in mind, type 11 and 13 listed are immediately rejected in the case of the solar house. Types 11 and 13 can be used for passive buildings as long as the walls will not be used as thermal mass.

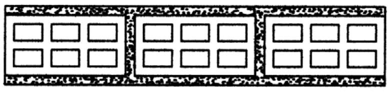
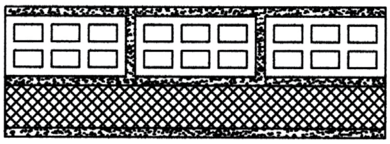
Since the U-value of the wall is an important factor, types 1, 3, 5, 7 and 9 are rejected since they have an unacceptable U-value.

Type 10 and 12 have an acceptable U-value, but the high manufacturing cost does not make them cost efficient.

The types 2, 4, 6, 7 and 8 are viable options. Type 6, 7 and 8 seem to be the best for the 25cm thickness of the concrete frame of the building (beams and columns). A better architectural design is achieved by avoiding the 5cm gap between the external walls and the columns and beams. With these comparisons in mind, the chosen type of wall construction for the Experimental Solar House is type 6, since it effectively insulates the whole structure and avoids thermal bridges where the columns and beams occur.

Roof construction: For the construction of the ESH two methods of roof construction were taken under consideration (Table 5.4). Upon further examination of all viable options for an efficient passive roof, the following solutions were considered.

For a passive building the structure need thermal mass in order to retain heat. With that in mind all three roof types are a viable option. Type 1 and 3 are the best. A better interior architectural design is achieved by using type 3, because of the reverse beam structure of the roof. Also a better insulation is achieved while avoiding the 5cm gap between the external walls and the columns and beams. The ESH uses type 3.

<table>
<tr>
<td>1. 100x100x300 brick, with three layers of plaster on both the interior and the exterior sides.
U-value 1.66 W/m²k</td>
<td>
</td>
</tr>
<tr>
<td>2. 100x100x300 brick and 70mm of expanded polystyrene on the exterior, with three layers of plaster on the interior and Adesilex FIS 13 on the exterior sides. The plastering on the exterior will be layered on a fibreglass mesh.
U-value 0.36 W/m²k</td>
<td>
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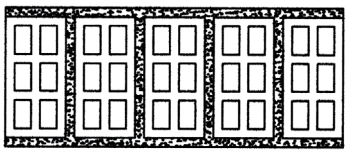
<tr>
<td>3. 100x200x300 brick, with three layers of plaster on both the interior and the exterior sides.
U-value 1.47 W/m²k</td>
<td>
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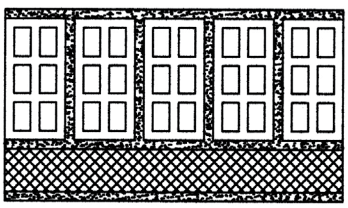
</tr>
<tr>
<td>4. 100x200x300 brick and 70mm of expanded polystyrene on the exterior, with three layers of plaster on the interior and Adesilex FIS 13 on the exterior sides. The plastering on the exterior will be layered on a fibreglass mesh.
U-value 0.31 W/m²k</td>
<td>
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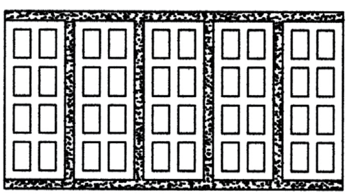
<tr>
<td>5. 100x250x300 brick, with three layers of plaster on both the interior and the exterior sides.
U-value 1.37 W/m²k</td>
<td>
</td>
</tr>
</table>

Table 5.1 Wall construction consideration methods

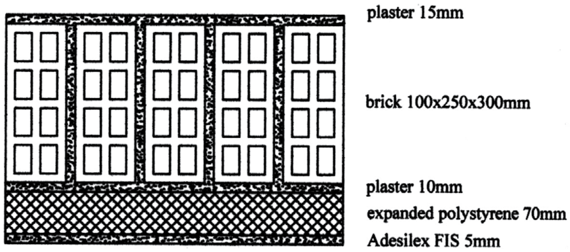
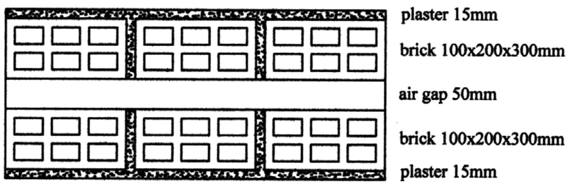
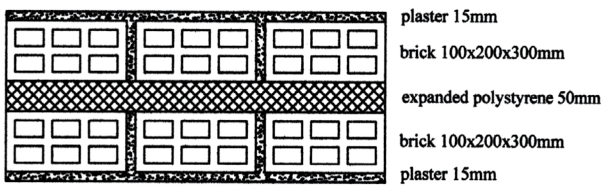
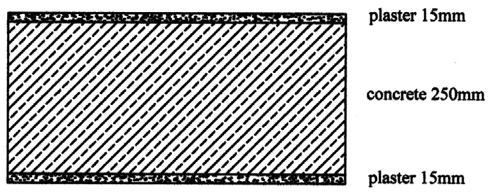
6. 100x250x300 brick and 70mm of expanded polystyrene on the exterior, with three layers of plaster on the interior and Adesilex FIS 13 on the exterior sides. The plastering on the exterior will be layered on a fibreglass mesh. U-value 0.296 W/m²k	
7. 250mm cavity brick wall. 100x100x300 brick on both sides and 50mm of air gap in between the walls, with three layers of plaster on both the interior and the exterior sides. U-value 0.9 W/m²k	
8. 250mm cavity brick wall. 100x100x300 brick on both sides and 50mm of expanded polystyrene in between the walls, with three layers of plaster on the interior and Adesilex FIS 13 on the exterior sides. U-value 0.314 W/m²k	
9. 250mm concrete wall, with three layers of plaster on both the interior and the exterior sides. U-value 3.22 W/m²k	

Table 5.2 Wall construction consideration method

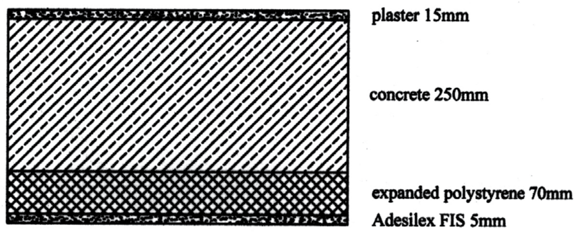
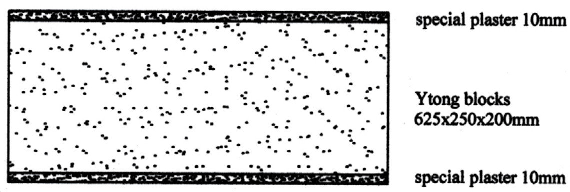
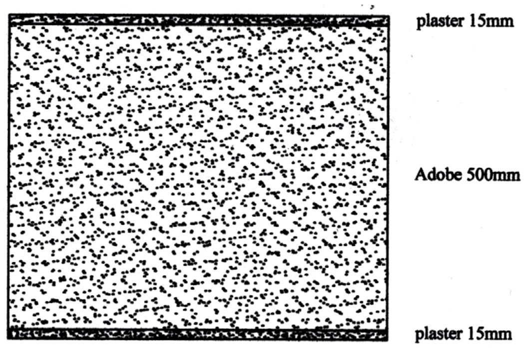
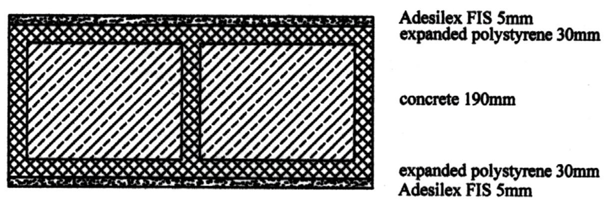
10. 250mm concrete wall and 70mm of expanded polystyrene on the exterior, with three layers of plaster on the interior and Adesilex FIS 13 on the exterior sides. The plastering on the exterior will be layered on a fibreglass mesh. U-value 0.4 W/m²k	
11. 62.5x25x20 Ytong blocks with two layers of special plaster on the inside wall and on the outside with a total price of 37.00 Cyprus pounds per square meter. U-value 0.29 W/m²k.	
12. 500mm adobe wall, with three layers of plaster on both the interior and the exterior sides. The plastering on the exterior will be layered on a fibreglass mesh. U-value 1.45 W/m²k	
13. Isorast, which is a lego type block made of polystyrene the cavities are then filled with concrete. 250mm cavity polystyrene wall. 30mm expanded polystyrene on both sides and 190mm of concrete in between the walls, with Adesilex FIS 13 on both the interior and the exterior sides. U-value 0.46 W/m²k	

Table 5.3 Wall construction consideration methods

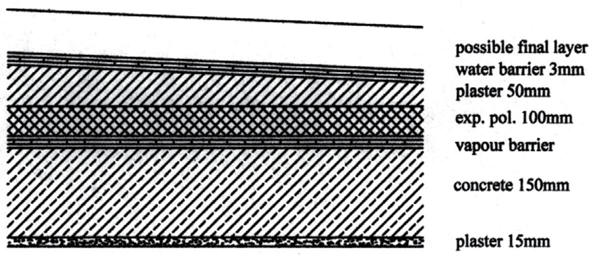
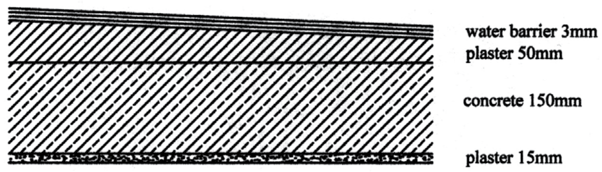
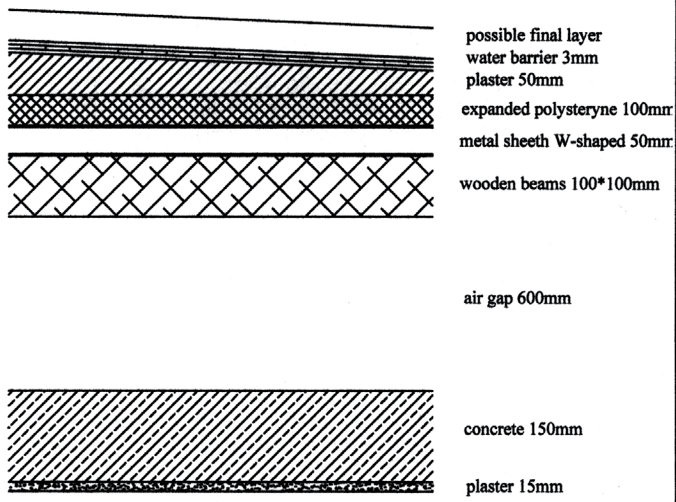
1. 150mm concrete, 3mm water insulation and 100mm of expanded polystyrene on the exterior, with three layers of plaster on the interior and 50mm on the exterior. U-value - 0.29 W/m²k.	
2. 150mm concrete, 3mm water insulation, with three layers of plaster on the interior and 50mm concrete on the exterior sides. U-value 3.03 W/m²k. (Figure 8.16)	
3. 150mm concrete, 600mm air gap, 3mm water insulation and 100mm of expanded polystyrene on the exterior, with three layers of plaster on the interior and 50mm on the exterior. U-value - 0.28 W/m²k. (Figure 8.15)	

Table 5.4 Roof construction consideration methods

Polystyrene as Thermal Insulation

Research on extruded and expanded polystyrene for the exterior surfaces of the building has being done by the author. From the research, it was concluded that expanded polystyrene is more cost effective and cheaper than extruded polystyrene. It is also manufactured in Cyprus while extruded has to be imported. Since one of the goals is to use materials that are derived from the local market, it was one more reason to use expanded polystyrene.

A comparison of different densities of expanded and extruded polystyrene was performed. The U-values of the polystyrene were compared with the thickness and costs on the different structures of the building: brick wall, roof, overhangs (on exterior floors), columns and beams. With respect to the type of polystyrene used, the following considerations were evaluated: based on the comparative research of the required structural thickness, against the unit price for several different polystyrene densities, it was determined that in order to meet the required proposed Cyprus Standards, polystyrene of weight 25kg/m3 was to be used (Lapithis, 2002).

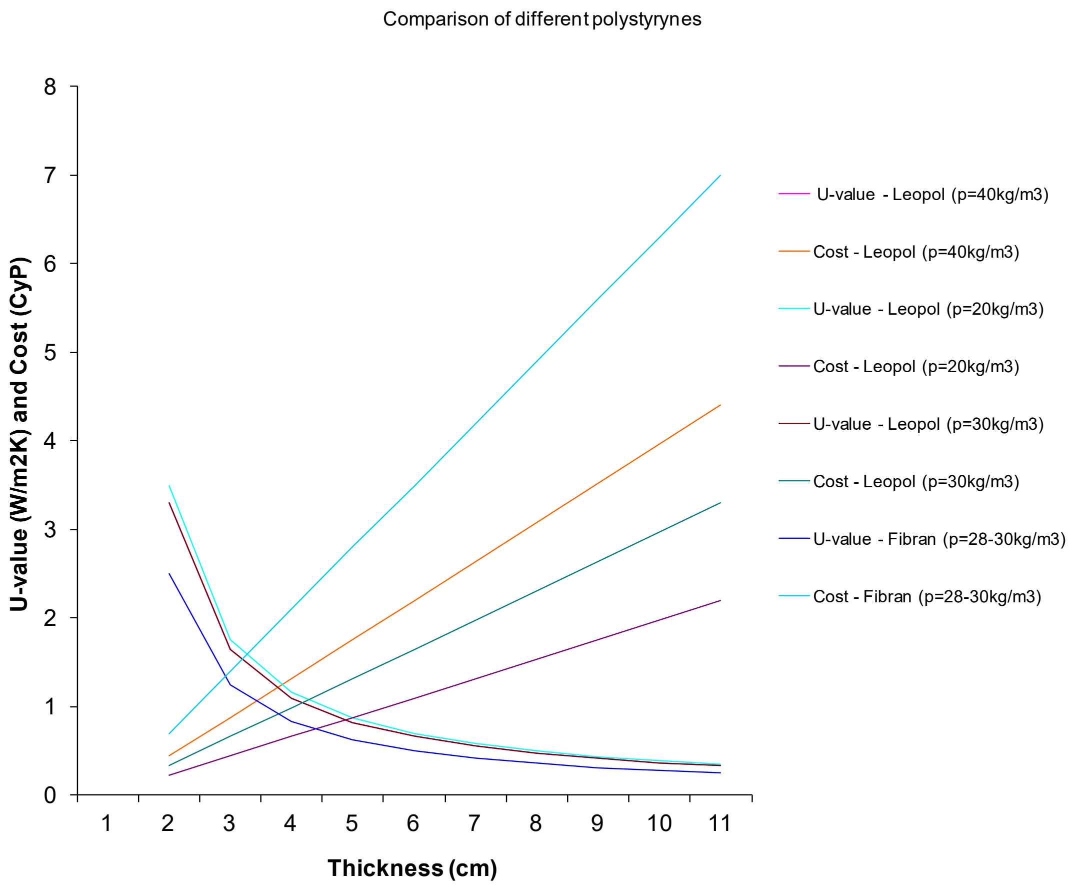


Figure 5.10 comparison of different densities of expanded and extruded polystyrene

ENERGY-10 Simulation Software

ENERGY-10 is a software used for a specific project and is designed to develop guidelines for low-energy buildings. It has been used by the author for the initial design concept of the Experimental Solar House. The evaluations were based on hour-by-hour calculations through all 8760 hours of the year, using simulation analysis. The weather data used were representative of typical conditions for the chosen location, which is Nicosia.

Its main features include daylighting, passive solar heating, and low-energy cooling strategies with energy-efficient shell design and mechanical equipment. The software requires and permits early decision-making during the design process. Energy-10's sustained performance estimate, although fairly accurate as a programme, is warned to be just an estimate. These estimates, by no means should be taken as certified predictions on the performance of the building. These uncertainties are due to the following factors:

- Depending on the work, movement and use of the building, it is impossible to tell during early stages of construction, how much energy the building as a whole, will consume. It has been estimated that occupant effects can result in an annual energy use that is anywhere from 70% to 140% of the average use in commercial and residential buildings. A major factor is also the amount of energy a consumer chooses to waste. Some tenants are careful about how long they will keep the heating or air-condition on, and have a keen sense of saving, both economically and ecologically. On the other hand there are also tenants, who prefer to pay a higher utility bill and use the buildings' heating and cooling systems freely. In other words each individual has different comfort zones.

- The energy estimates are based on long-term average weather and solar data but it is very possible that weather conditions during any one-year can be very different from the long-term average.

- It is impossible to predict the usage of internal gains - especially plug loads. This suggests a significant uncertainty to forecasting energy use.

- Errors may be observed in the input data due to variations between the descriptions and how the building is actually constructed, or inaccuracies in the analysis procedures used in the programme.

Contemporary House vs Traditional House

In order to place a contemporary house into perspective, one must exhibit the comparison between the energy performances of a contemporary house, one that was built post 1970, as it relates to its counterpart, a house built with older building techniques, in the traditional way. The most important difference in the construction specifications of these houses, as they are portrayed here in the construction of the traditional house's wall (adobe versus concrete and bricks) and in the roof (earth versus concrete). The traditional house and the contemporary house follows the characteristics discussed in

earlier chapters. It transpires from the results produced, that the energy performance of the organically insulated traditional house is clearly superior than that of the contemporary house with no energy-efficient considerations.

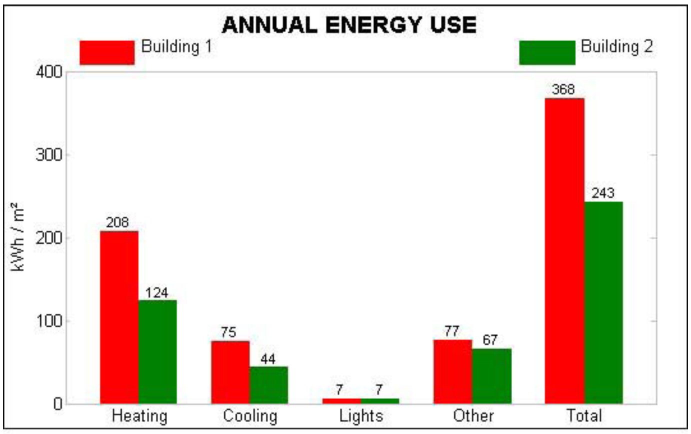


Figure 5.11 Contemporary house vs traditional house energy use comparative bar graphs

Experimental Solar House vs Contemporary House

As was expected, upon comparing quantitatively the Experimental Solar House with the contemporary house, the solar house proves to be far superior in its energy savings performance. The overall energy requirements for the contemporary house, according the Energy 10 calculations, reaches a high of 368 kWh/m^2 as compared to 121kWh/m^2 of the Experimental Solar House.

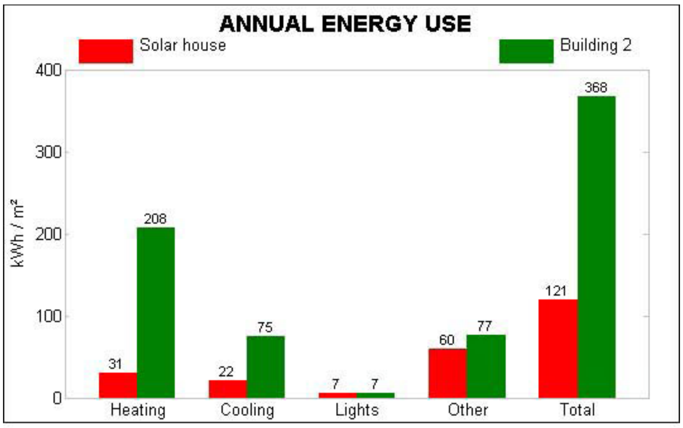


Figure 5.12 ESH vs contemporary house energy use comparative bar graphs

Experimental Solar House vs A Low-Energy Case

APPLY is a special feature of Energy-10 that provides a quick way for the designer to ascertain the combined effect of a group of candidate strategies. APPLY automatically makes global modifications in a building description. These modifications are made based on the user selection of any or all of the Energy Efficient Strategies (EES), and the

user-defined characteristics of each of those strategies. Both selections are made under the EE Strategies menu. The APPLY feature has produced a most valuable comparison between the low energy scenario and the Experimental Solar House. Interestingly enough, the performance of the Experimental Solar House and of the APPLY house is very similar overall. Certain values of the Experimental Solar House show better performance (e.g. the annual cost breakdown) and in other cases, the APPLY house comes out ahead (e.g. total energy use). It can be concluded that the Experimental Solar House has competed successfully with the APPLY house.

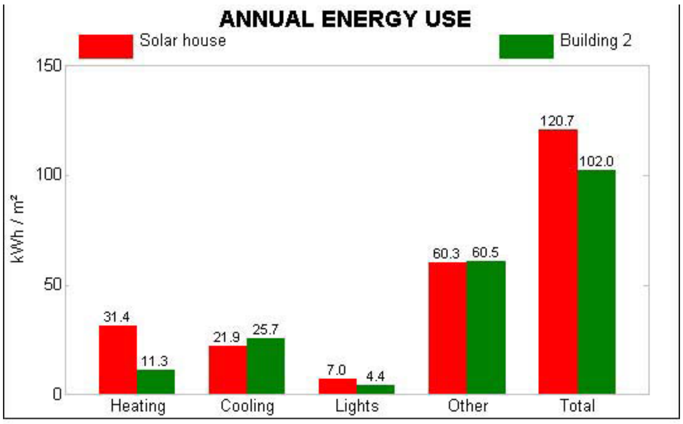


Figure 5.13 ESH vs low energy house energy use comparative bar graphs

Weather Tool Analysis Programme

The Weather Tool (Marsch, 1990) is an analysis programme for hourly climate data. It's database stores a wide range of international weather file formats and provides display options, wind roses and sun-path diagrams, for the best possible climactic understanding in the chosen location. In addition the programme includes a mechanism for defining the relative potential of different passive designs. Solar radiation analysis, optimum orientations for specific building design criteria are accurately determined. The programme therefore functions as a pre-design analysis tool. The following figures illustrate the comfort percentages before and after the following passive systems were insulated. Comfort percentages change dramatically once these passive systems are inserted:

- Thermal mass effects
- Exposed mass and night purge ventilation
- Passive solar heating
- Natural ventilation
- Direct evaporative cooling
- Indirect evaporative cooling, demonstrating

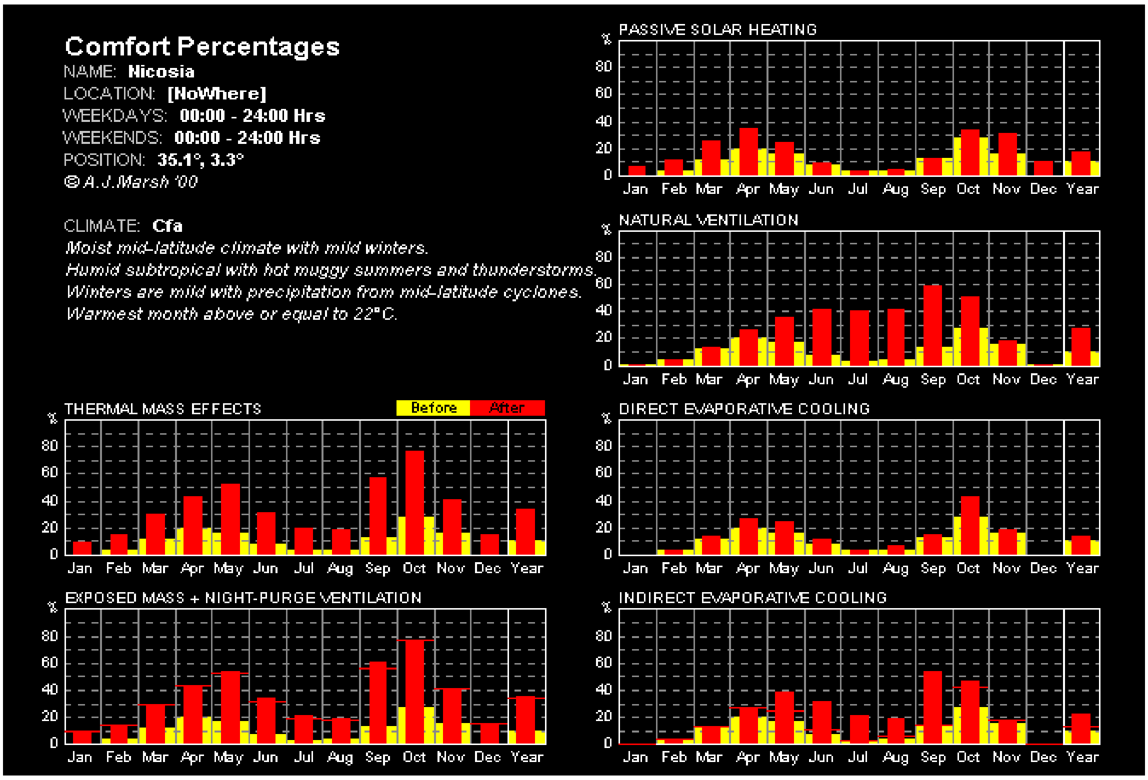


Figure 5.14 Analytical Comfort percentages of selected design techniques

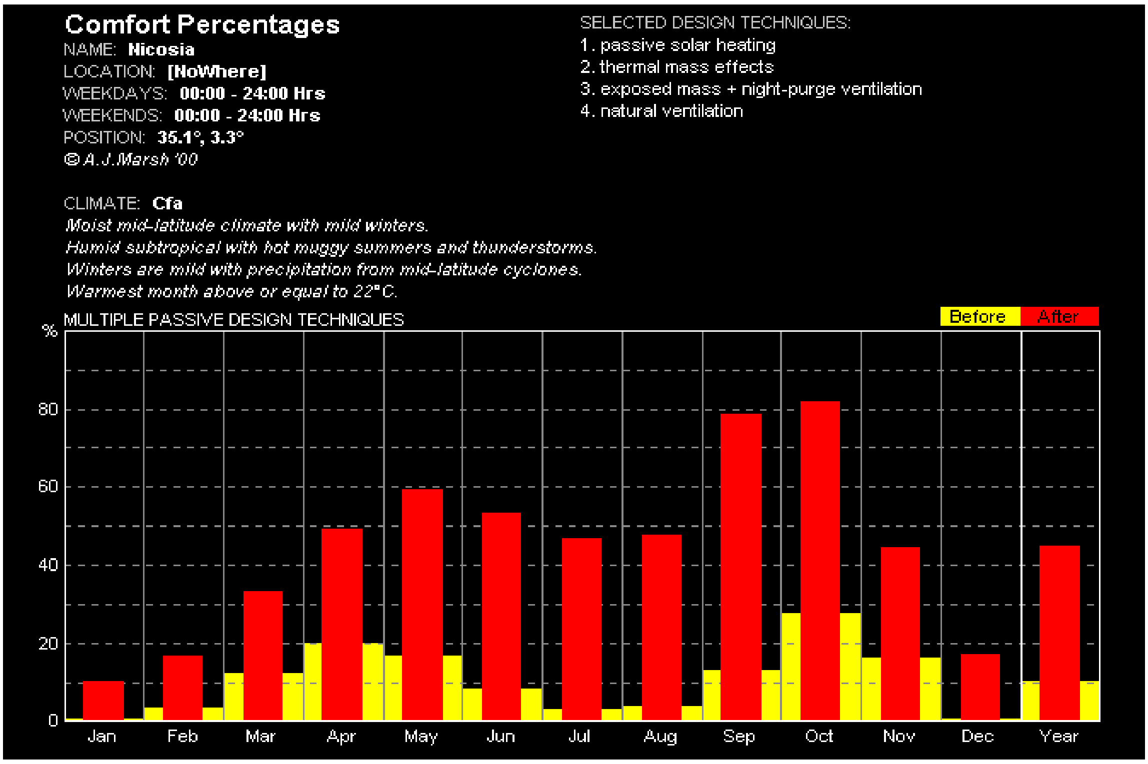


Figure 5.15 Analytical Comfort percentages of selected design techniques

Construction of the Experimental Solar House

The following photos are the construction phases of the house from the beginning until the end.

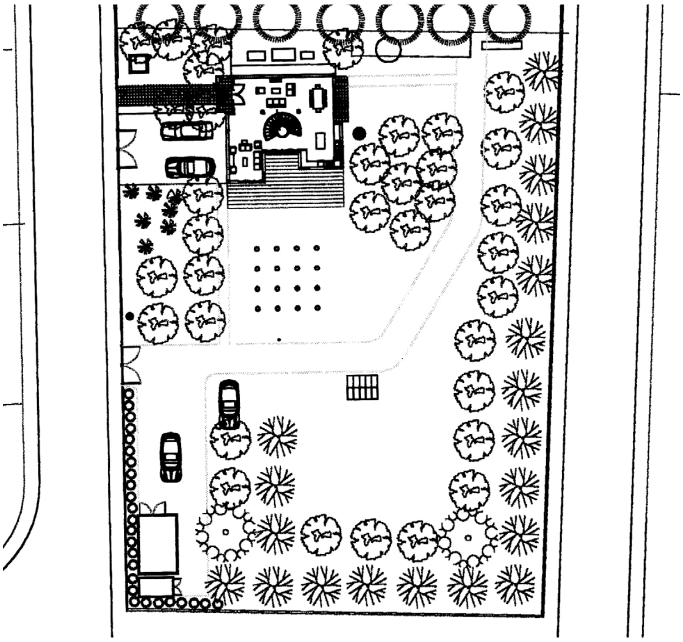


Figure 5.16 Site and neighbourhood

Photo 5.1 Site and neighbourhood

Photo 5.2 Foundations (typically executed)

Photo 5.3 Brick work

Photo 5.4 Electrical Installation

Photo 5.5 Staircase with toilet beneath, showing heavy mass construction

Photo 5.6 Exterior thermal insulation walls

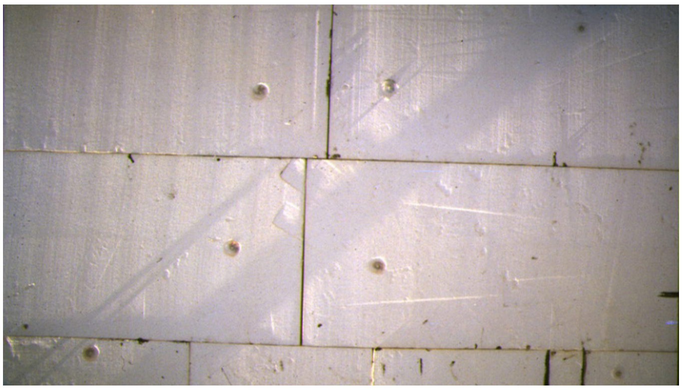


Photo 5.7 Thermal insulation wall, spanning the entire house

Photo 5.8 Insulation and plastering of walls

Photo 5.9 Insulation and plastering of roof light construction

Photo 5.10 Roof construction, an air cavity of 60cm is between the concrete roof, assuring better roof insulation

Photo 5.11 Roof construction, placing the 10cm thick insulation

Photo 5.12 Roof constructed, showing roof light facing south

Photo 5.13 Water sewage treatment, tanks placed on the north side

Photo 5.14 interior originally painted with warm colours. Later the author decided to repaint all white to ensure better dispersion of light

Photo 5.15 Master bedroom and Jacuzzi (north and west)

Photo 5.16 Master bedroom (south wall)

Photo 5.17 The bedroom is facing the south-east, and the windows shown are facing true south in order to maximise southern isolation. (east and south wall)

Photo 5.18 Kitchen (north and east)

Photo 5.19 The fireplace is made of cement plastering so as to retain the heat when the fire is lit. This way, heat is retained even after the fire is out. External openings in the lower body of the fireplace suck in cold air, heat it and release it from top openings, using the thermosyphon system. Fireplace (north wall)

Photo 5.20 East window and west door natural ventilation

Photo 5.21 Staircase and clerestory window

Photo 5.22 Staircase bottom

Photo 5.23 Clerestory window and southern window

Photo 5.24 South facade and photovoltaic tracking system which follows the movement of the sun

Photo 5.25 The small openings on the north wall are for ventilation purposes. West and north façade.

Photo 5.27 South and east facade

Photo 5.26 The twin pergola is used for both levels to protect from the southern summer sun (west and south facade)

Photo 5.27 Thickly carpeted living room

Photo 5.28 Pergola shading 50% of the window during the winter, eliminating solar radiation

Monitoring of the Experimental Solar House

Detailed monitoring has been typically conducted over long periods of time, ranging from an entire heating season or cooling season to several years. Recently developed methods of performing short-term monitoring during the heating and cooling season and extrapolating the performance over the entire season have reduced the time and cost required for monitoring. At the very least, electrical and fuel bills can be monitored. They can be used for a cursory examination of the house's thermal performance.

Proponents of passive solar buildings knew from the outset that before this energy saving concept could be widely accepted, its effectiveness had to be thoroughly demonstrated and documented. Therefore, since the late 1970s many governments, utilities, and private associations have mounted research and development programmes, which included major field studies to monitor the thermal performance of passive solar homes. These programmes have involved the collection and analysis of measurements of selected energy performance indicators, using complicated and expensive instrumentation.

"Energy saved" is also a complex quantity, the immediate question being "Compared to what?" A reference building with energy performance characteristics typical of conventional houses in that area must be specified for this purpose. Another difficulty with this measure is that the comparison between two buildings is only meaningful if the same energy quantities are compared under the same operating conditions. Obviously, operating conditions can vary greatly, due to weather and particularly, as seen later on, due to occupant behaviour, which affects temperatures to which the building is heated, internal heat gains, occupancy schedules, and many other factors.

These variations make it impossible to simply compare total metered energy consumption, or even sub metered space-heating energy. At a minimum, a consistent energy savings calculation must account for the effects of variations of weather, by accounting for outdoor temperature variations, and for occupancy factors by accounting for variations in indoor temperatures and internal heat gains.

This section provides a commentary to the monitoring charts compiled over a period of 24 months - from 27/11/1999 until 18/10/2000 and from 21/1/2001 until 18/12/2001 in the ESH. It also presents the monitored results on the thermal comfort charts showing the effectiveness of the ESH.

In December 1999, a series of data collecting loggers were installed in five locations in the solar house (one in each bedroom, one in the open plan living room and one in a shaded location outdoors), which monitored temperature and relative humidity every hour. The wind velocity was measured using the anemometer outdoors.

The data was retrieved by means of the management software GLM, which is run on a Microsoft Windows based host computer. Data is exported from the loggers into the software in the text formats ready for importing into a spreadsheet or other programmes. The software has the capacity to store 7900 data readings along with such information as the logging interval and description together with the details of the in-

dividual logger including the unique serial number. The output graphs are shown in this chapter.

Concerning internal data collecting loggers, provisions should have been made for them to be positioned out of direct sunlight and not on outside walls or heavy weight walls, which may provide local disturbance. According to the Environmental Committee (1983), an acceptable position is at a point 1.6m above the floor and below the head of any door so as to avoid the layer of hot air that often occurs above the door head height and out of direct draughts. There is evidence to suggest that the boundary layer thickness of air at a wall is about 15cm from the wall so that the sensor should be positioned at least this distance from the wall. For the external probe, provision was made for it to be shielded from solar radiation. Unfortunately in the Experimental Solar House the internal data loggers were placed at a point 2.5m above the floors and placed directly on the wall. They were placed on the interior walls and direct sunlight was avoided.

It should be noted that the author did not inhabit the ESH until the last week of April 2000. During the time prior to habitation from December 1999 until April 2000, the doors and windows of the house remained closed. The Venetian blinds and pergola were not installed. There were infrequent visits from construction workers during this period for some final construction details. The temperature and RH data loggers in the ground floor (living room) in the year 2001 were damaged. Unfortunately this was seen when the readings were been downloaded into the software. For this reason no readings have been taken for this year for the living room. Taking the readings of the year 2000 into account, it can be considered that no difference is seen between other rooms.

Temperature

Hourly temperature readings were taken all year round. Specified 24 hours period each month are plotted on graphs. During the months prior to habitation, December 1999 until April 2000, the temperatures succeeded in remaining constant in a twenty-four hour period, ranging from 1 to 1.5^{0}C from room to room. It is noted that overall the indoor temperatures are kept in the thermal comfort requirements

The temperatures achieved during the winter months and March 2000(16^{0}C) were approximately 6^{0}C higher than the average 24-hour temperature outdoors. It is important to note that the maximum difference in temperature between indoors and outdoors was up to 10^{0}C.

The house was first inhabited in May 2000. The daytime external temperature reached approximately 28^{0}C and the night-time temperature was 14^{0}C. The indoor temperature, however, remained steady at around 22^{0}C. In June the daytime indoor temperatures were unsatisfactorily high. The reason for this sudden raise indoor temperature was the daytime opening of windows and doors thus allowing heat to enter. As the temperature rose, the absence of Venetian blinds and the pergola resulted in the recording of higher temperatures.

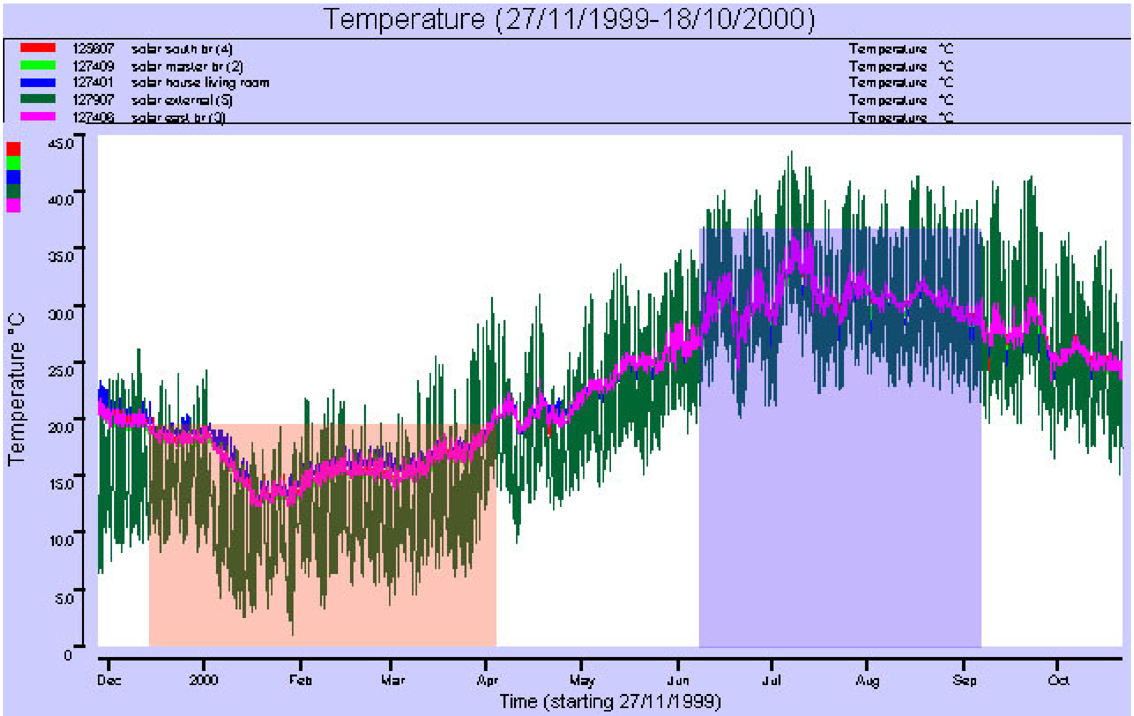


Figure 5.17Temperature. November 1999 - October 2000. Non Habitation Period

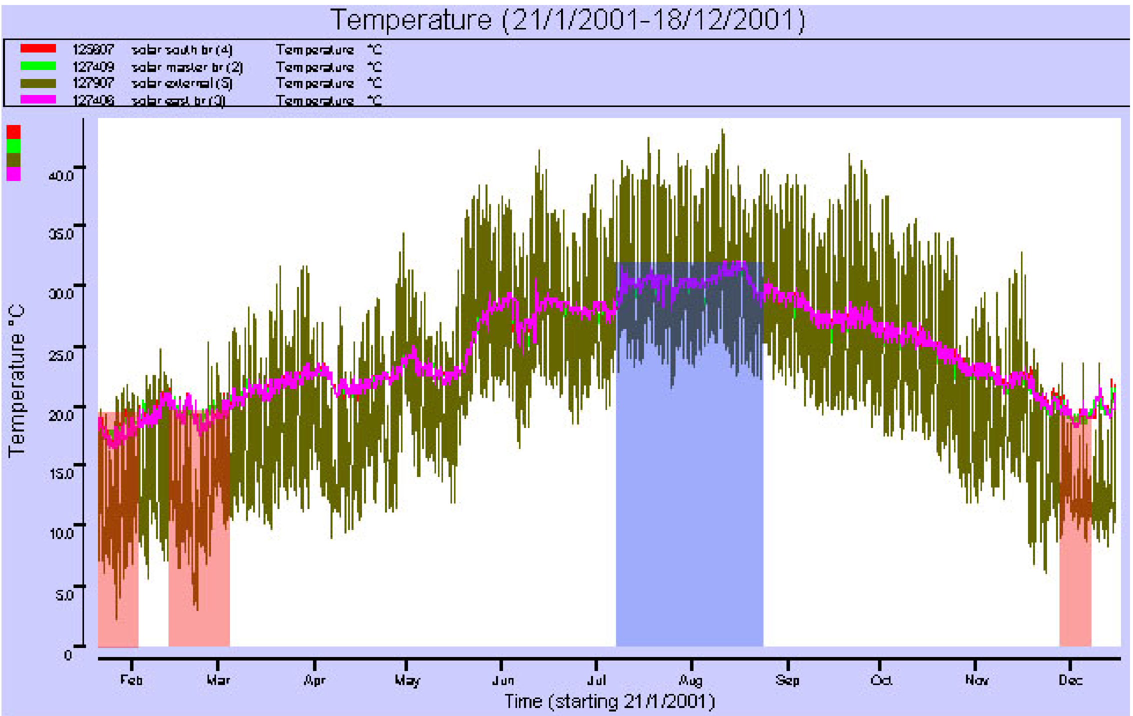


Figure 5.18 Temperature. January 2001 - December 2001. Habitation Period

Comparison of House Functions Between Years 2000 and 2001:

- The Experimental Solar House was occupied in April 2000 therefore heating wasn't needed in the early winter months (January – March). However figure 5.17 monitors the indoor and external temperatures throughout the year 2000. Therefore, according to figure 5.17 heating was theoretically needed from the 15th Dec – 30th March. This relatively large need, is however partially due to the fact that the house was still in its construction stages, and doors and windows were occasionally left open. Figure 5.17 unfortunately shows that data was not collected from the 19th October till the 20th January. This is because the batteries of the data collectors had ran out and were not noticed till the end of January 2001.

- In the year 2001 heating was needed from the 15th January till the 10th February, from the 15th February till the 3rd of March and from the 28th November till the 5th of December (figure 5.18)

- According to Olgyay's comfort zone (21°C) heating would be needed from the 5th January till the 10th March and from the 17th November till the 12th December.

- In December 1999, the house was uninhabited, closed and without furniture (carpets, paintings, pergola). The indoor temperatures range was within the comfort zone (fig 5.17), showing that once the above errors are corrected; the Experimental Solar House will function within the comfort zone.

- Figures 5.17 and 5.18 show the heating and cooling needs in the year 2000 and 2001. The pink line shows the internal temperatures throughout the year. Once this line drops below 19.5°C heating is needed (shown in red), and once the line rises above 29°C cooling is needed (shown in blue). There are moments during the heating and cooling seasons (red and blue) where the fireplace and fans are not needed, as temperatures rise and drop accordingly. The external temperatures are shown in green (year 2000) and brown (year 2001).

- Overall, the 24hour indoor measurements indicate a variation of 0-2°C temperature swing. Taking into account that the external temperature swing is 10-15°C, this shows that a constant temperature is preserved throughout the day.

- The graphs clarify the steady difference, throughout a 22-month time-line. It is clear that room temperatures within the house, remain relatively steady throughout all months, and are constantly within the comfort zone limits.

- The need for cooling (use of ceiling fans) rises when temperatures rise above the comfort zone levels i.e. above 29°C. Figure 5.17 shows that fans needed to be used from the 15th June till the 5th September in the year 2000.

- Figure 5.18 shows that fans needed to be used from the 5th July till the 20th August in the year 2001. The external temperatures remained the same for both years. However the internal temperature in the year 2000 reaches its peak at 36°C, while in the year 2001 the internal temperature reaches its peak at 31°C. Thus consideration is

needed as to why the internal temperature rose to such an extent in the year 2000.

- The difference lies in the insertion of shading devices. In the year 2000 the Venetian blinds and the pergola were not placed in the house, while in the year 2001, the shading devises were used, thus proving the importance of shading devices within the house, during the summer.

- Hypothetically, in the future, the indoor temperature may drop to an approximate of 28°C, as the vegetation around the house will grow satisfactorily. Should vegetation not be an option, other external shading devices, which can be used, include wooden louvres or shutters

- The need for heating (fireplace) rises once temperatures drop below the comfort zone levels i.e. below 19.5°C.

Monthly Temperatures

Further on are the monthly temperate zones from November 1999- December 2001

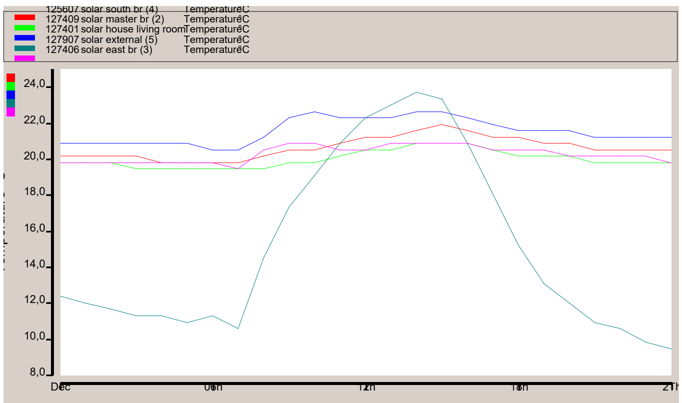


Figure 5.19 Temperature. December 1999. Non Habitation Period

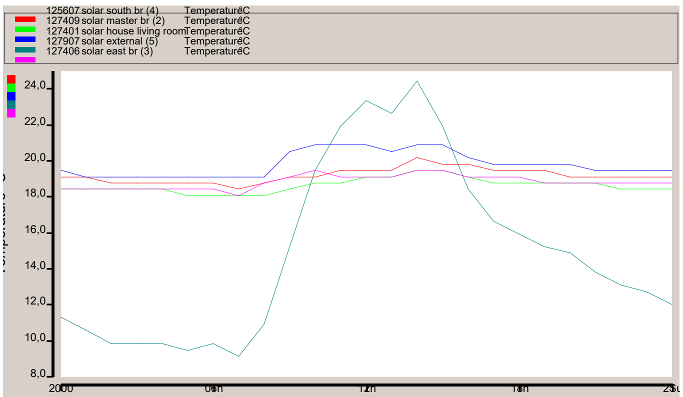


Figure 5.20 Temperature. January 2000.Non Habitation Period

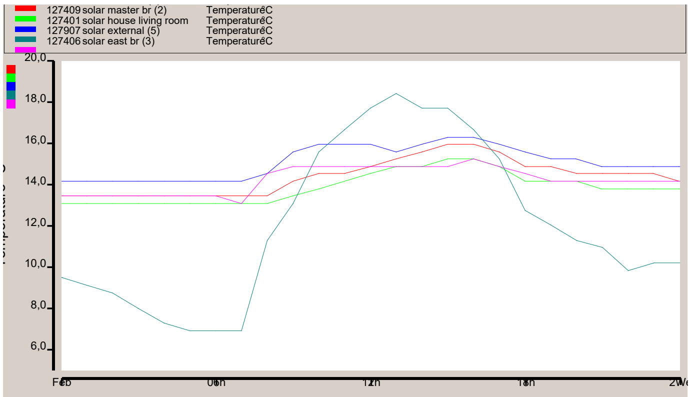


Figure 5.21 Temperature. February 2000.Non Habitation Period

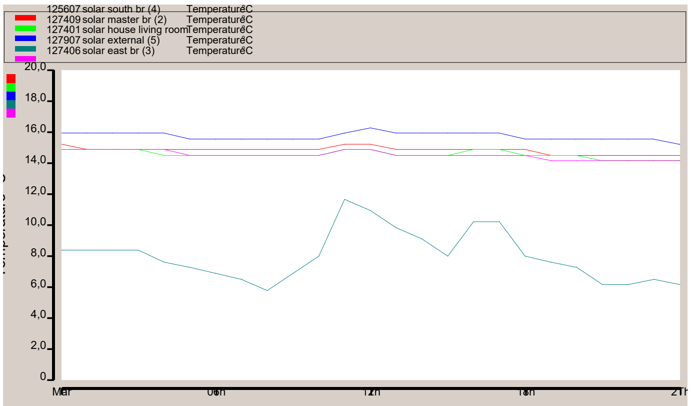


Figure 5.22 Temperature. March 2000. Non Habitation Period

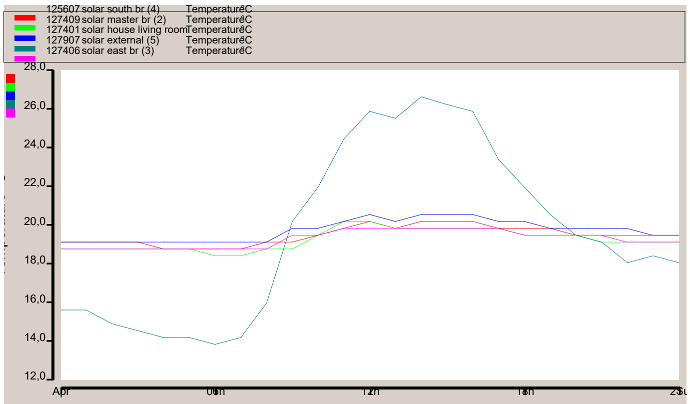


Figure 5.23 Temperature. April 2000. Non Habitation Period

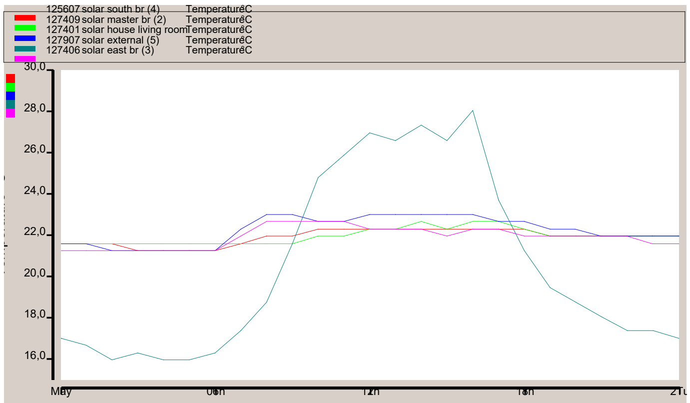


Figure 5.24 Temperature. May 2000. Habitation Period

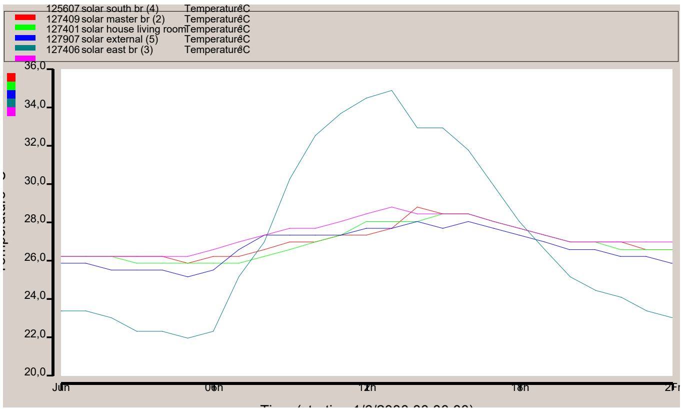


Figure 5.25 Temperature. June 2000. Habitation Period

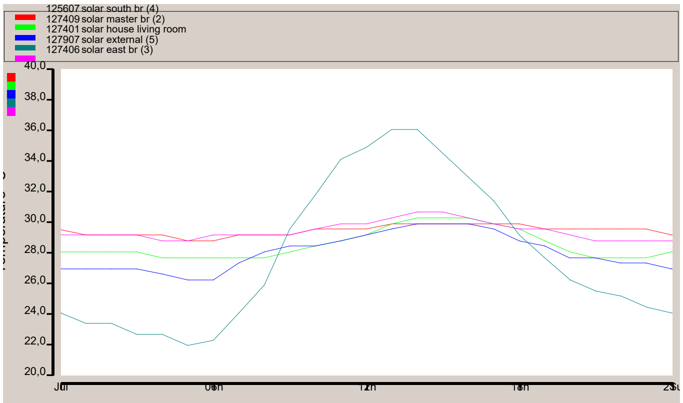


Figure 5.26 Temperature. July 2000. Habitation Period

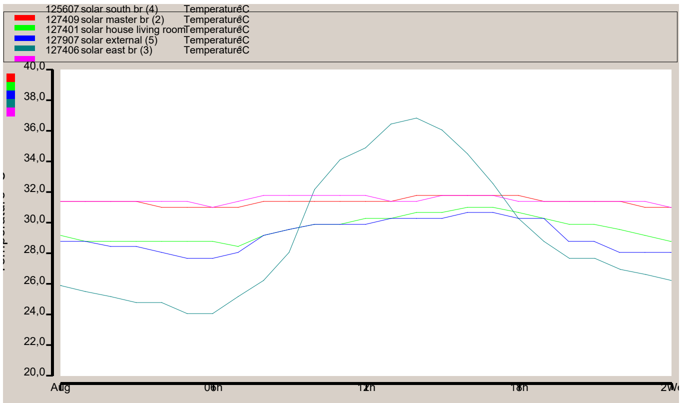


Figure 5.27 Temperature. August 2000. Habitation Period

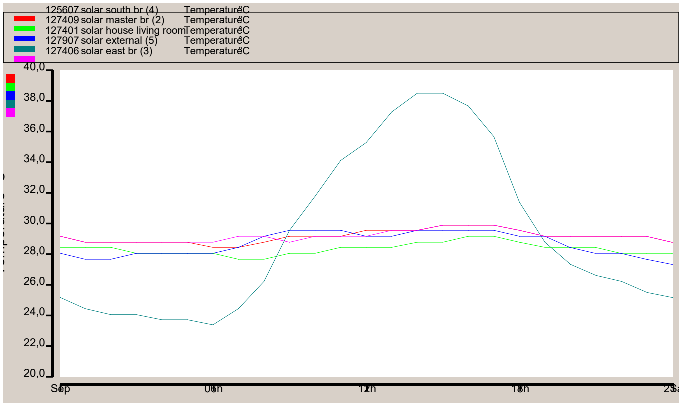


Figure 5.28 Temperature. September 2000. Habitation Period

Figure 5.29 Temperature. October 2000. Habitation Period

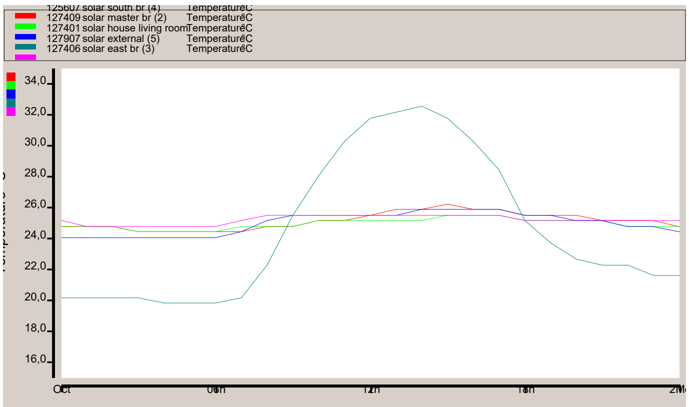


Figure 5.30 Temperature. February 2001. Habitation Period

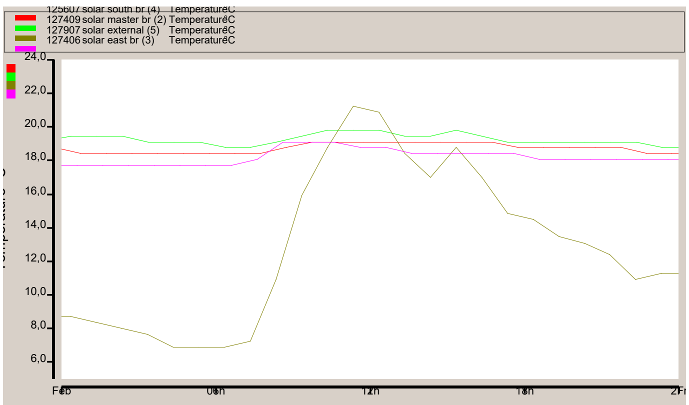


Figure 5.31 Temperature. March 2001. Habitation Period

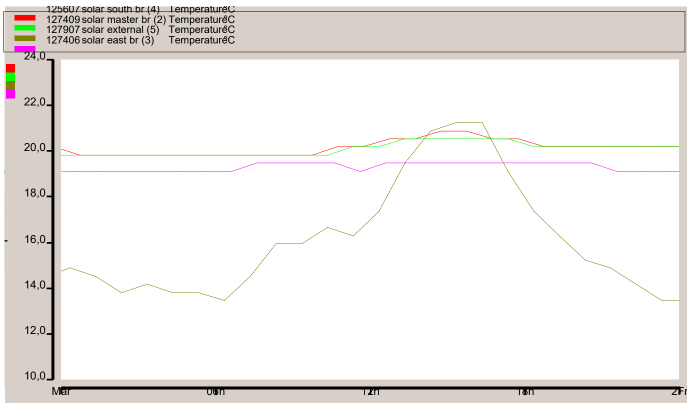
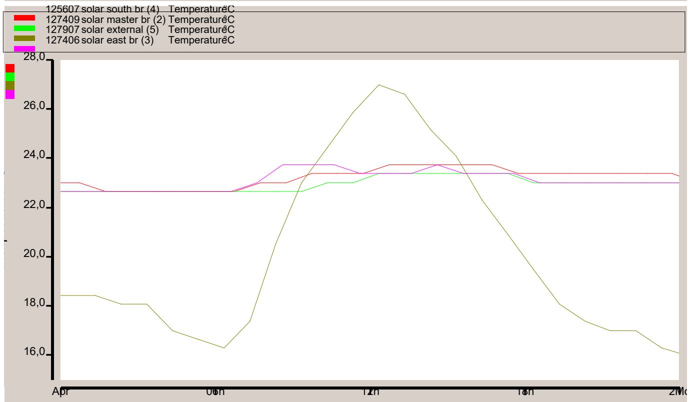


Figure 5.32 Temperature. April 2001. Habitation Period



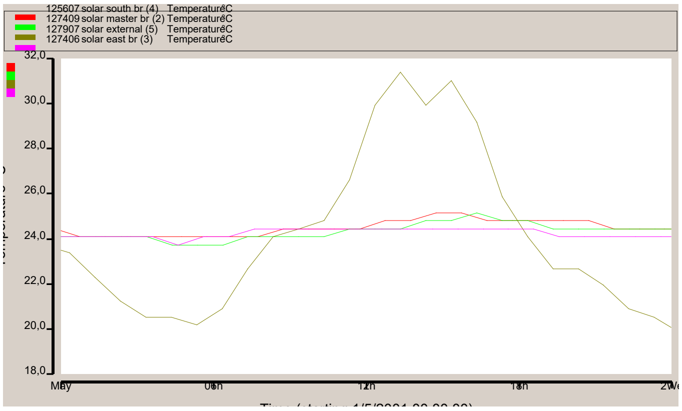


Figure 5.33 Temperature. May 2001. Habitation Period

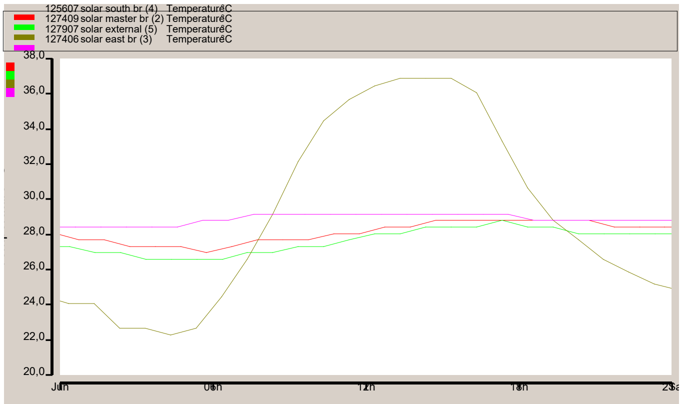


Figure 5.34 Temperature. June 2001. Habitation Period

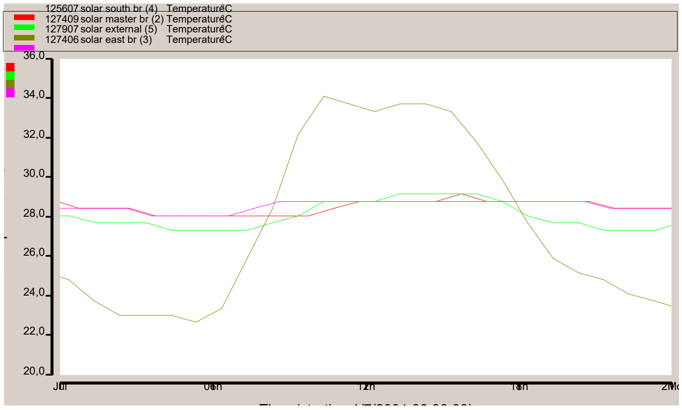


Figure 5.35 Temperature. July 2001. Habitation Period

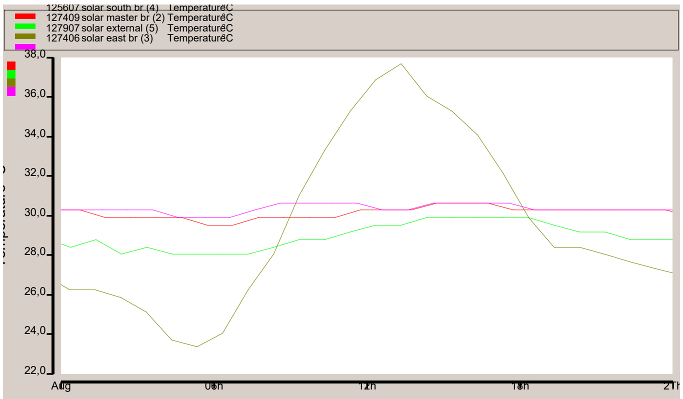


Figure 5.36 Temperature. August 2001. Habitation Period

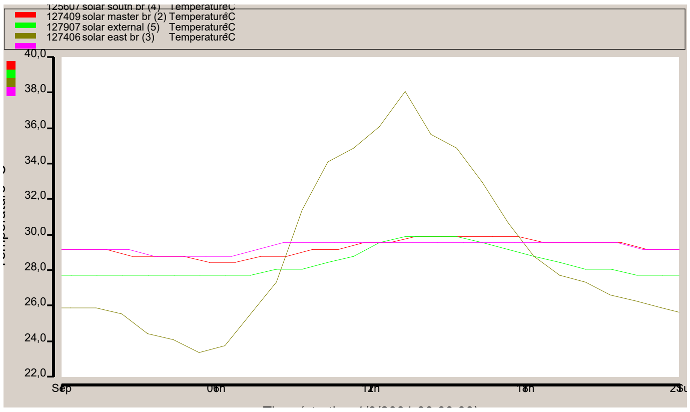


Figure 5.37 Temperature. September 2001. Habitation Period

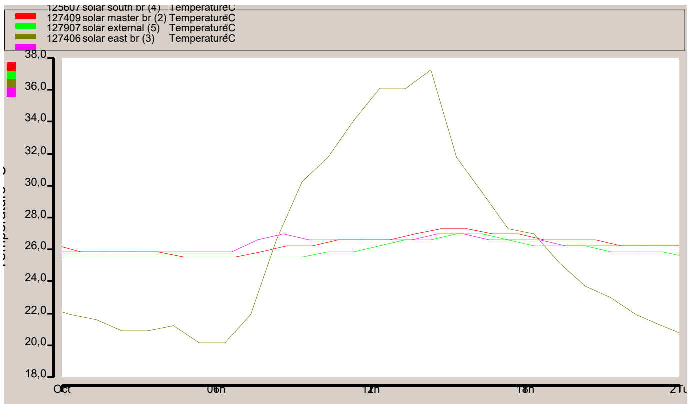


Figure 5.38 Temperature. October 2001. Habitation Period

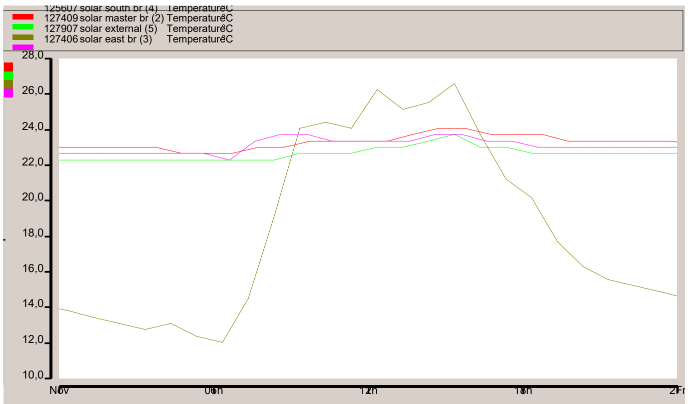


Figure 5.39 Temperature. November 2001. Habitation Period

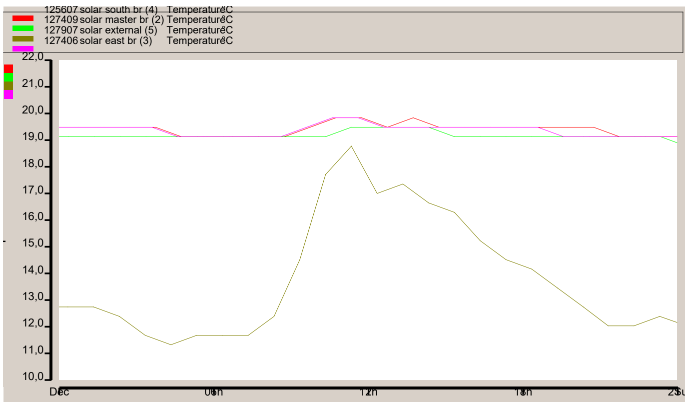


Figure 5.40 Temperature. December 2001. Habitation Period

Summer Daytime and Night Time Ventilation

The months of July and August 2000 showed much more variation, since this period of time was used to experiment with various ventilating combinations of open and closed windows. This experimentation was aimed towards the theory that during the summer months, the best cooling method is night ventilation.

- Temperature and relative humidity monitoring from July 27th until August 5th 2000 showed that when day ventilation occurs then the inside temperatures are high.

- The chart shows that during the first days when day ventilation occurs, inside temperatures are up to 35°C (27-31 July), while when there is no day ventilation then the inside temperature does not exceed 29°C (1-5 August).

- It is also noted that on August 1st the inside temperature is 32°C, which is the mid temperature between the time day ventilation stopped. The reason for this is the thermal mass of the house, which needed 24 hours to cool down. The same can be seen for relative humidity.

- Should the windows be kept open not only during the night, but during the day as well, the space will overheat. Once this was proven empirically, the windows were kept closed during the day.

- As the daytime outdoor temperatures rose to the high thirties, the indoor temperature rose approximately 2°C during the day reaching a high of 29°C, and then dropped again to an average of 27°C at night.

- August 2000 temperatures (28°C) were kept more constant than the months before, since night ventilation schemes were executed and the shading devices were operated more rigorously.

- There is a clear difference between the external temperature and the internal. As well as being steadier, the indoor temperatures show a much lower contrast than the outdoor temperatures.

- The same results apply for the relative humidity, measured during the same dates.

- The following graphs indicates the temperature levels for the dates 27.7.2000 till 5.8.2000 within the ESH.

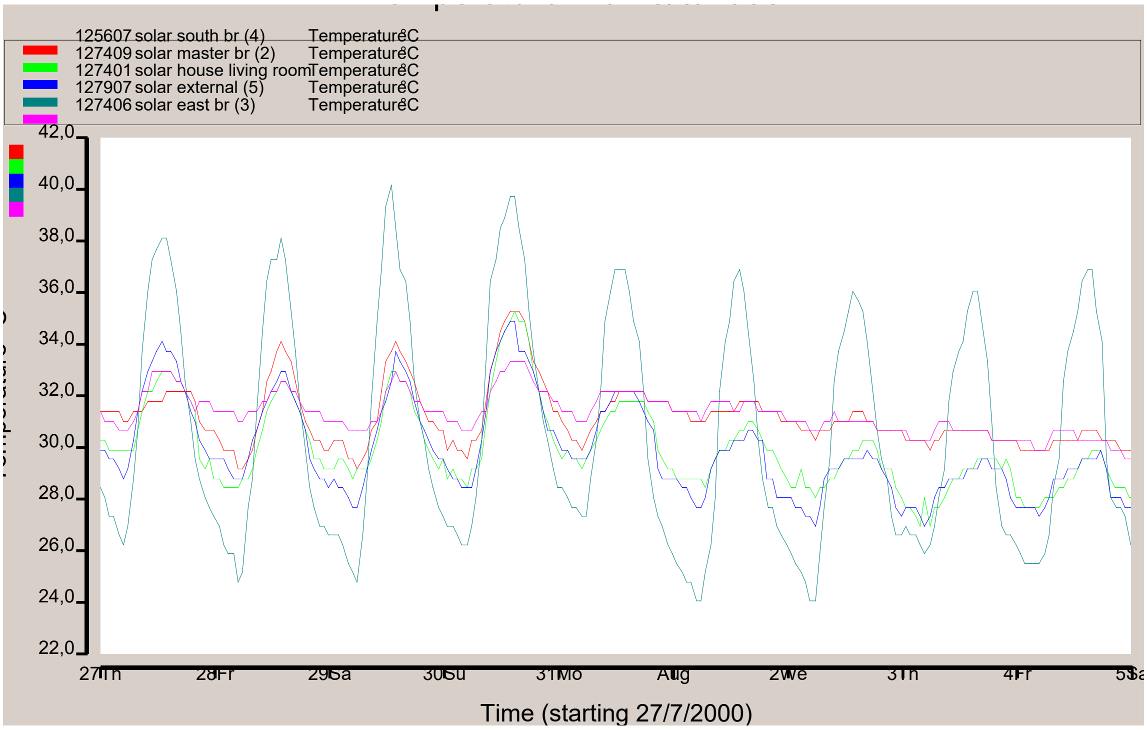


Figure 5.41 Temperature. Night time and Day time Natural Ventilation. 27 Aug-5 Sept

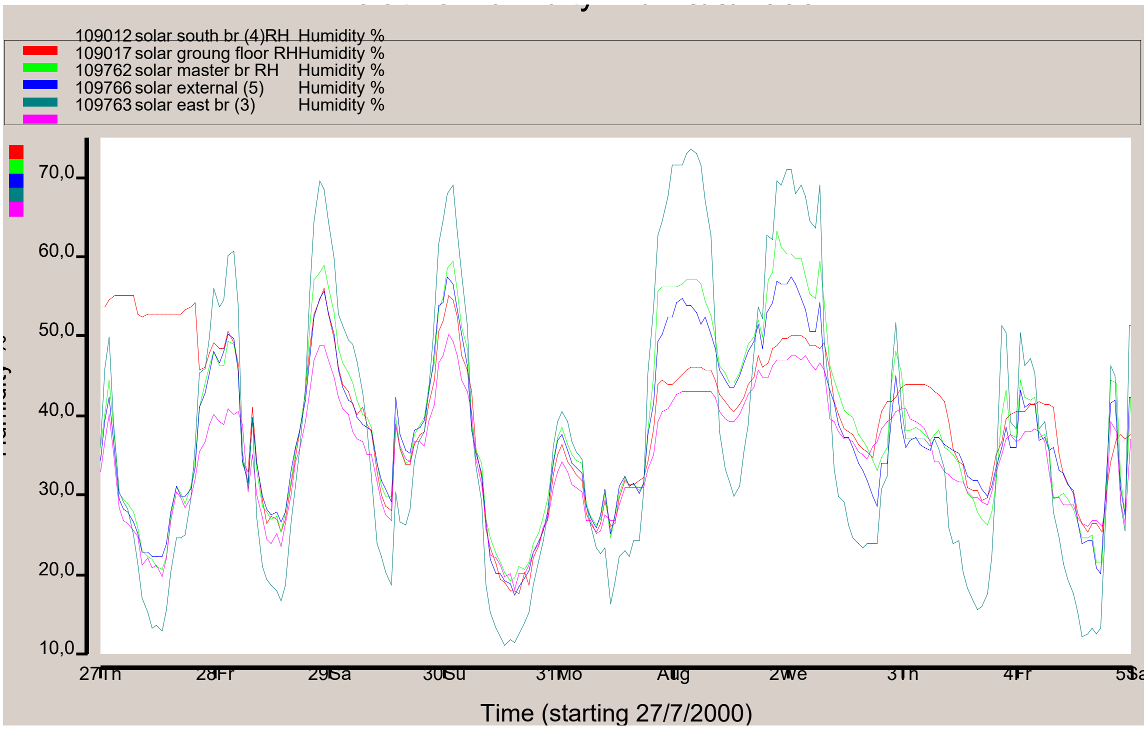


Figure 5.42 Relative Humidity. Night time and Day time Natural Ventilation. 27 Aug-5 Sept

Relative Humidity

It should be noted that inland area humidity levels in Nicosia are distinctly lower than those in coastal areas. Humidity was kept at constant levels during the months prior to habitation with a maximum of 65% in January and February 2000 and a minimum of 45% in December 2000. Outdoor humidity levels during those months fluctuated greatly during the day, sometimes as much as 50% during the course of twenty-four hours.

In April 2000 and more so in the months that followed, humidity levels showed as much fluctuation during a twenty-four hour period as the outdoor humidity levels, with the peak and the lowest values kept at less extreme values indoors.

Most of the measured room relative humidity lies within a zone of 5% around the measured RH curve for the day. The average differences of the measured relative humidity between the rooms for each hour range between 0 and 5%. In most cases positive differences are found during the day and negative during the night indicating relative humidity during the day and underestimates them at night. It is noted that overall the indoor relative humidity is kept within the thermal comfort requirements, which shall be discussed further on showing each month's mean relative humidity.

Overall, the 24 hour measured indoor relative humidity has a variation of 2-20% relative humidity swing. Taking into account that the external relative humidity swing is 20-60%, this shows that a constant relative humidity remains preserved all day long.

The following graphs indicate the annual relative humidity for the years 2000 and 2001. Further on, monthly indications are illustrated, but it is important to note the overall image the graph bares. Through this indication, the ESH has proven to preserve a roundabout ideal temperature and humidity throughout the year.

The following graphs indicate the monthly relative humidity percentages of the solar house, from the beginning of the year 2000 until the end of the year 2001. Familiar steadiness can be noted, as well as boundary limits within the comfort zone. The graphs are colour charted in the following scheme:

Red: Ground Floor

Green: Southern Bedroom

Purple: Master Bedroom

Pink: East Bedroom

Blue: External (1999-2000)

Yellow: External (2001)

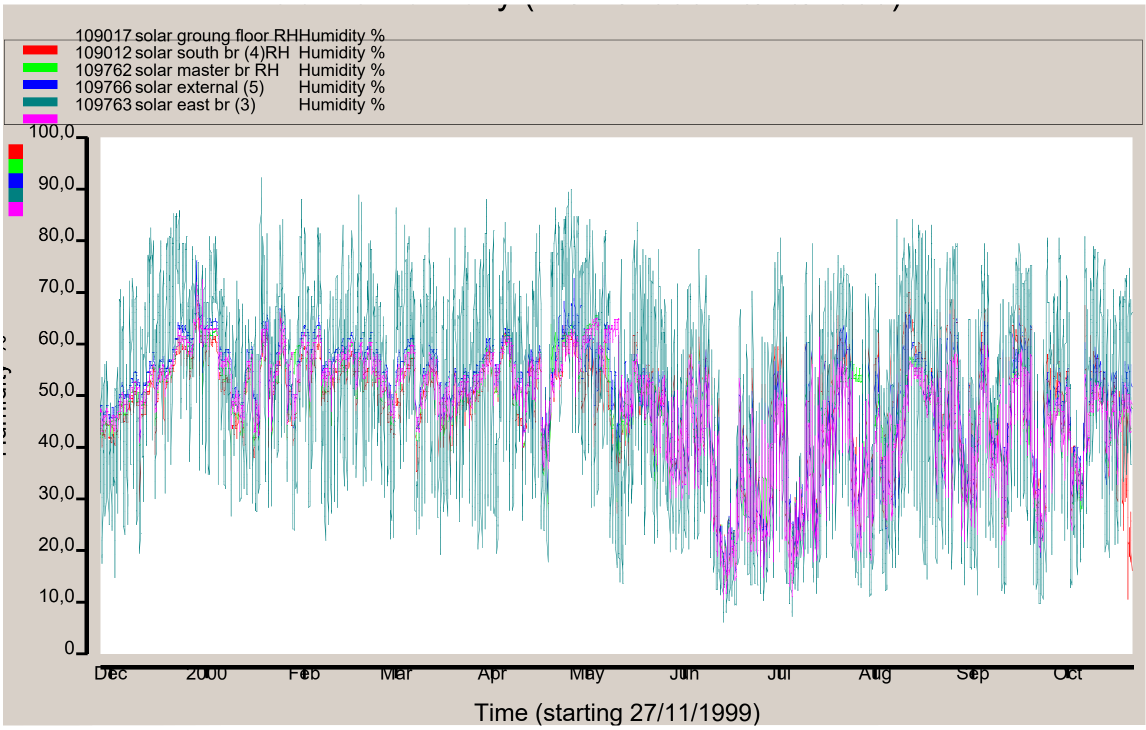


Figure 5.43 Relative Humidity. November 1999 - October 2000. Non Habitation Period

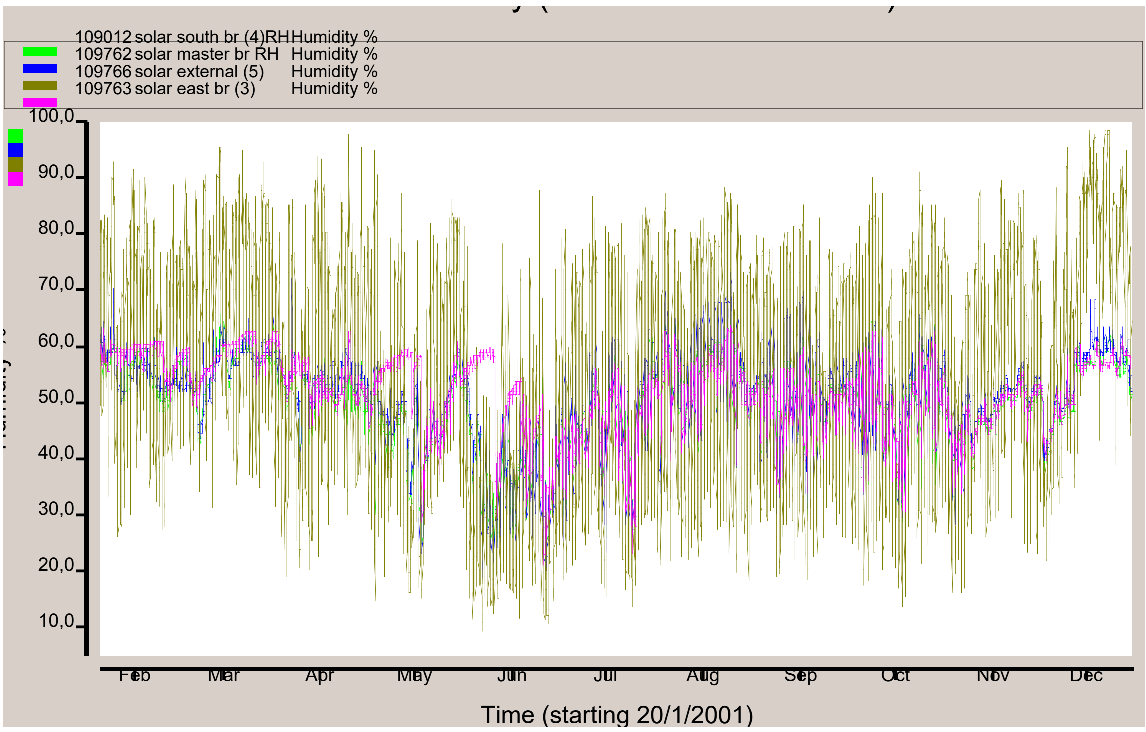


Figure 5.44 Relative Humidity. January 2001 - December 2001. Habitation Period

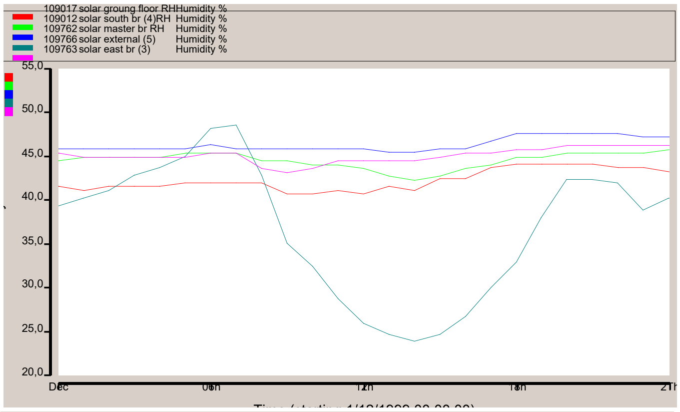


Figure 5.45 Relative Humidity. December 1999. Non Habitation Period

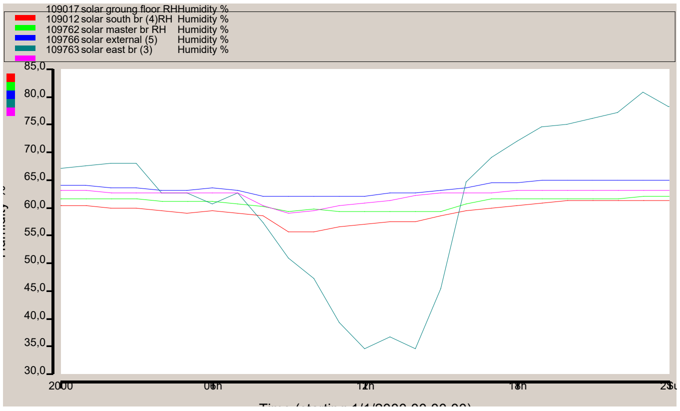


Figure 5.46 Relative Humidity. January 2000.Non Habitation Period

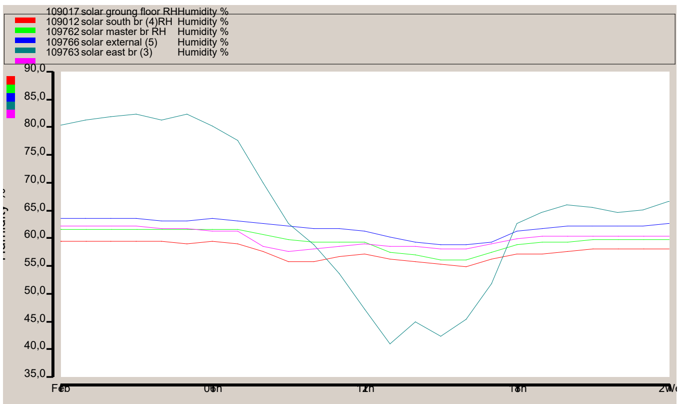


Figure 5.47 Relative Humidity. February 2000.Non Habitation Period

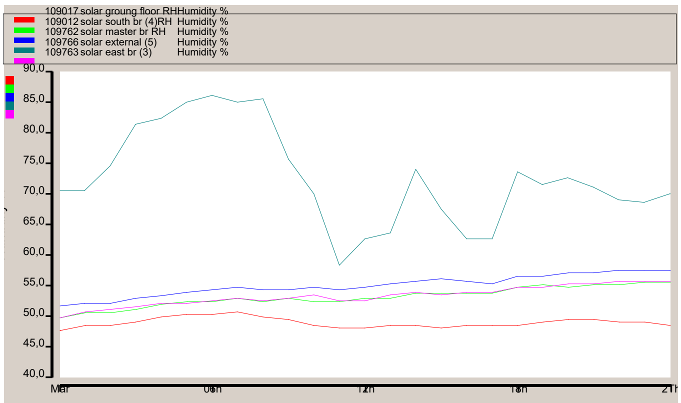


Figure 5.48 Relative Humidity. March 2000. Non Habitation Period

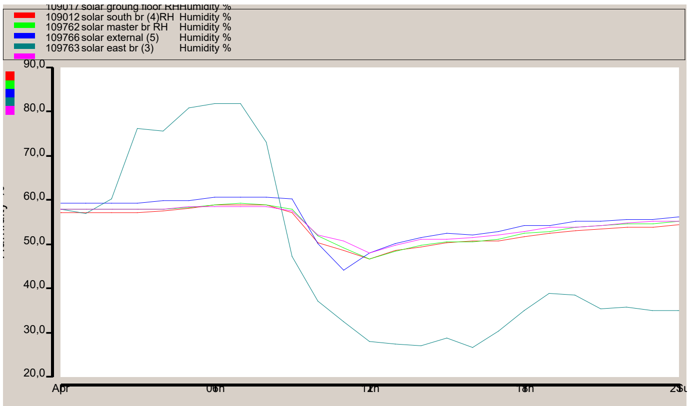


Figure 5.49 Relative Humidity. April 2000. Non Habitation Period

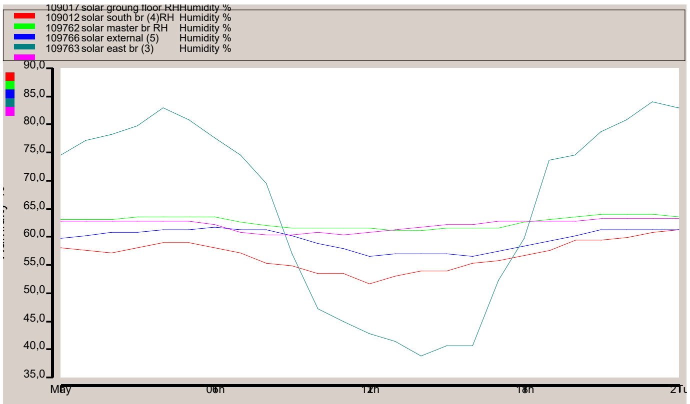


Figure 5.50 Relative Humidity. May 2000. Habitation Period

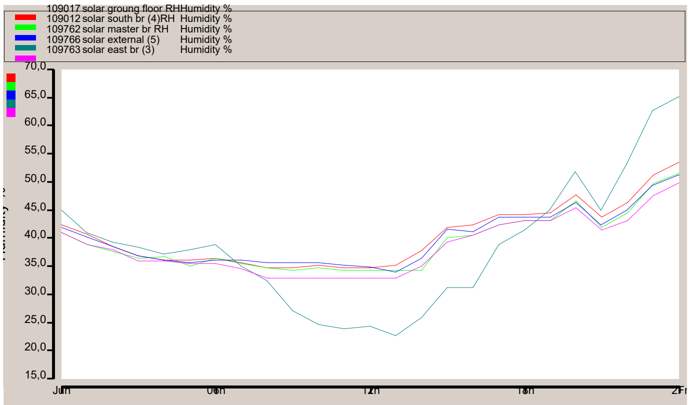


Figure 5.51 Relative Humidity. June 2000. Habitation Period

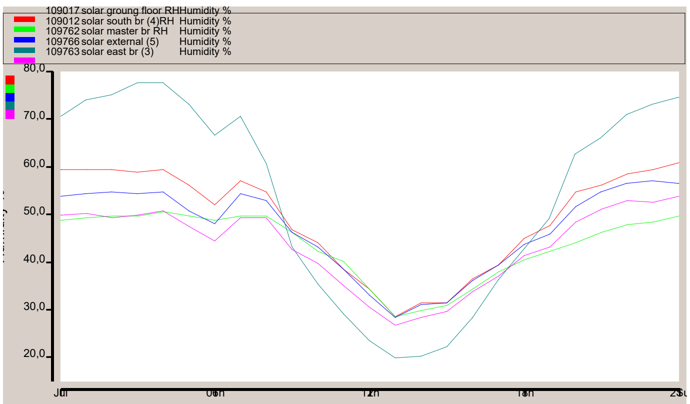


Figure 5.52 Relative Humidity. July 2000. Habitation Period

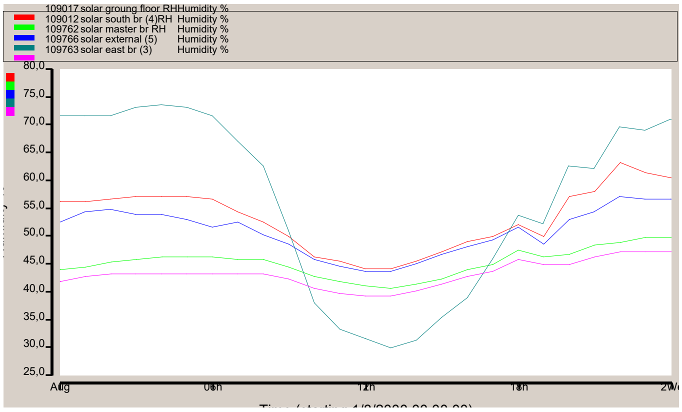


Figure 5.53 Relative Humidity. August 2000. Habitation Period

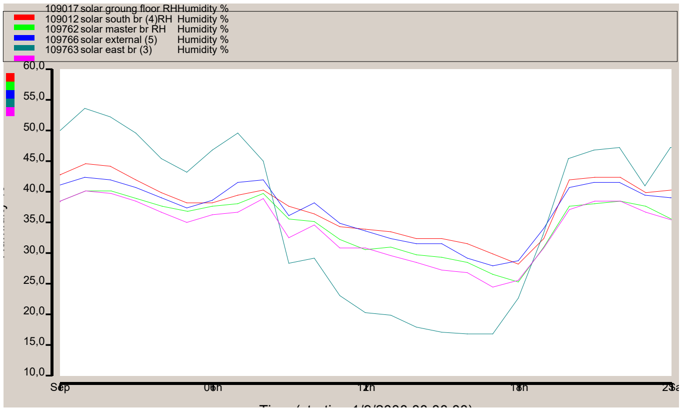


Figure 5.54 Relative Humidity. September 2000. Habitation Period

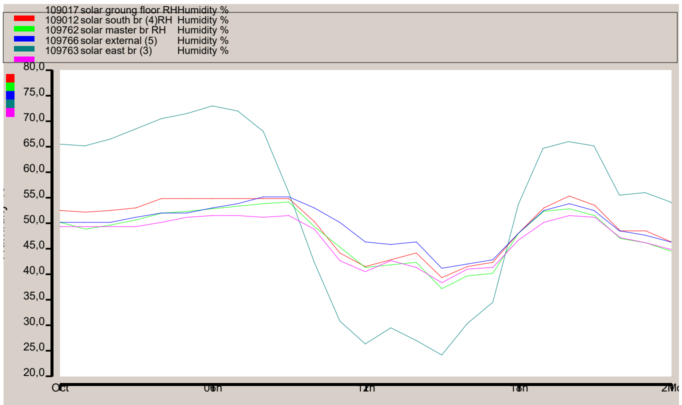


Figure 5.55 Relative Humidity. October 2000. Habitation Period

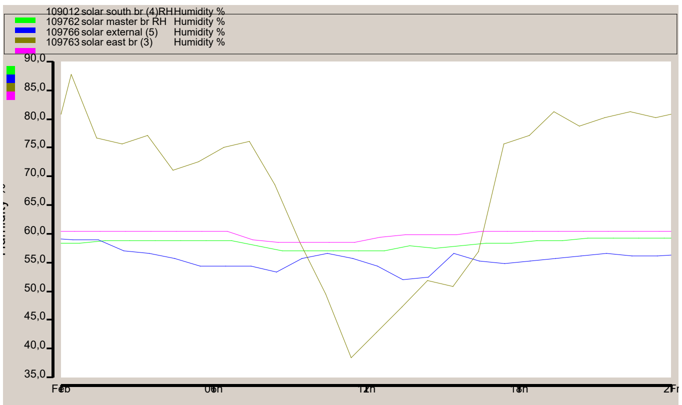


Figure 5.56 Relative Humidity. February 2001. Habitation Period

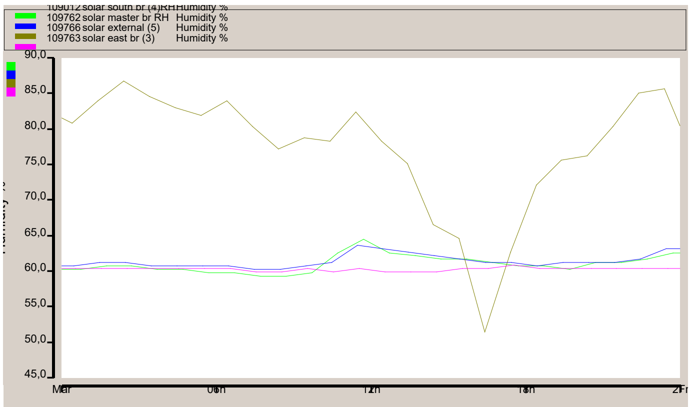


Figure 5.57 Relative Humidity. March 2001. Habitation Period

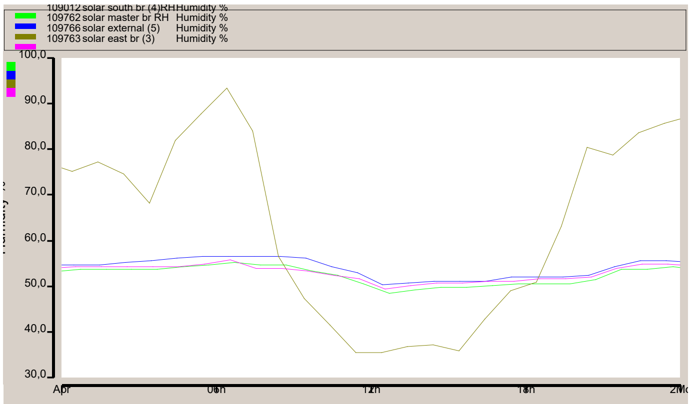


Figure 5.58 Relative Humidity. April 2001. Habitation Period

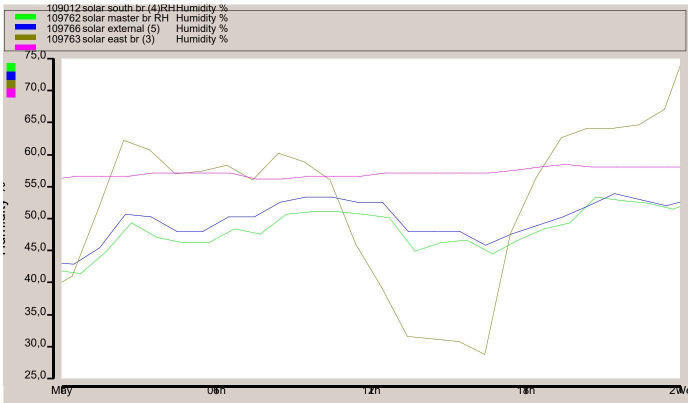


Figure 5.59 Relative Humidity. May 2001. Habitation Period

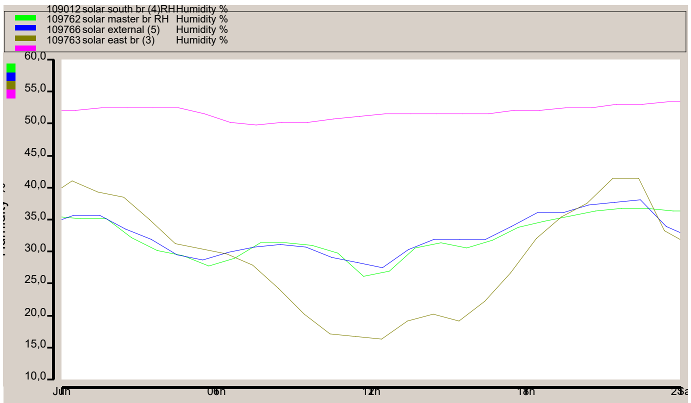


Figure 5.60 Relative Humidity. June 2001. Habitation Period

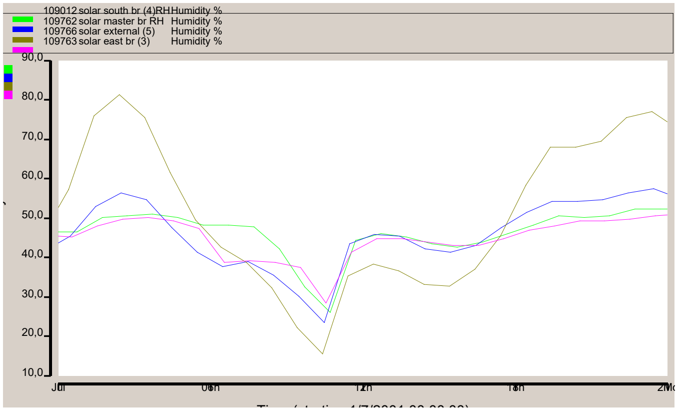


Figure 5.61 Relative Humidity. July 2001. Habitation Period

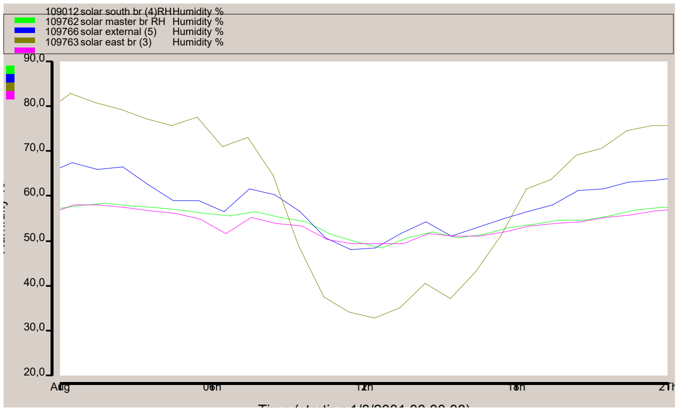


Figure 5.62 Relative Humidity. August 2001. Habitation Period

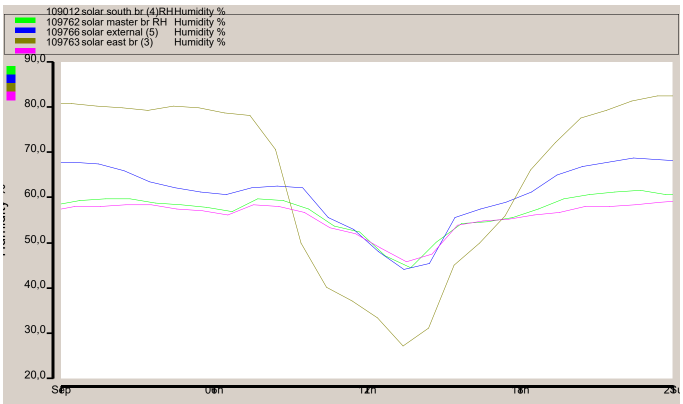


Figure 5.63 Relative Humidity. September 2001. Habitation Period

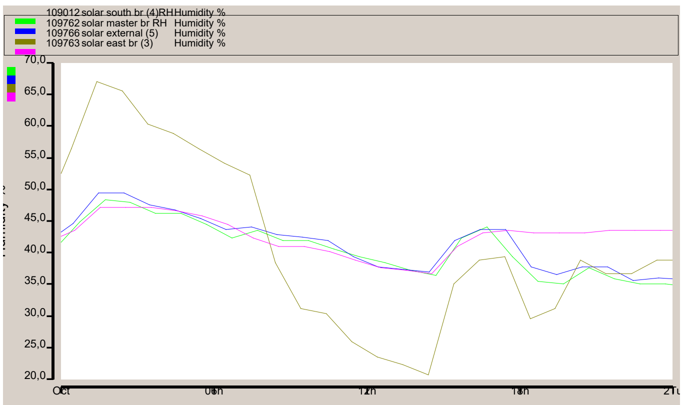


Figure 5.64 Relative Humidity. October 2001. Habitation Period

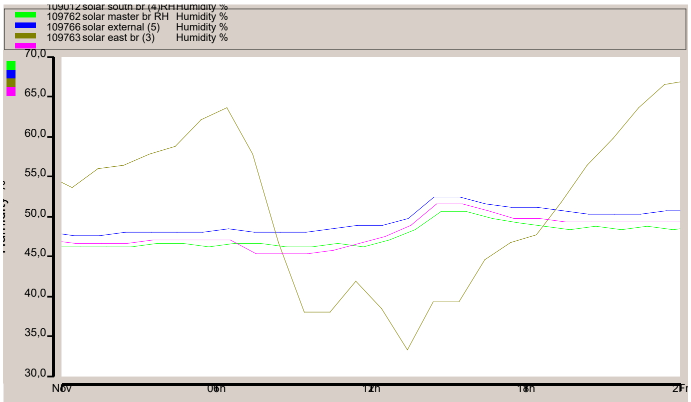


Figure 5.65 Relative Humidity. November 2001. Habitation Period

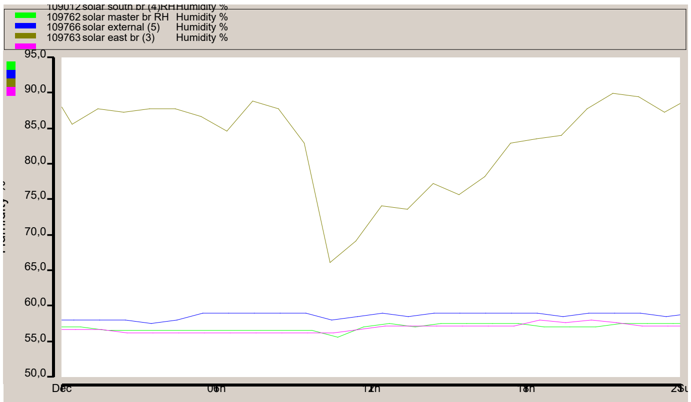


Figure 5.66 Relative Humidity. December 2001. Habitation Period

Wind Data

In addition to the temperature and humidity data collected, a small weather station (Weatherlink, 1991) is located on the roof of the house. The weather station has been recording the wind direction and velocity by a wind vane and an anemometer respectively.

The data is recorded on an hourly basis and exported to the computer software Weatherlink version 4.04 (Weatherlink, 1991).

The data collected from the small weather station of the Experimental Solar House prove that the location of the windows was correct, since they match the data considered initially.

Two examples of the wind data collected are shown in Figures 5.67 and 5.68. Figure 5.67 shows results taken from the 2nd till the 4th of August 2000 and the Figure 5.68 shows the compiled results for the entire month of August 2000.

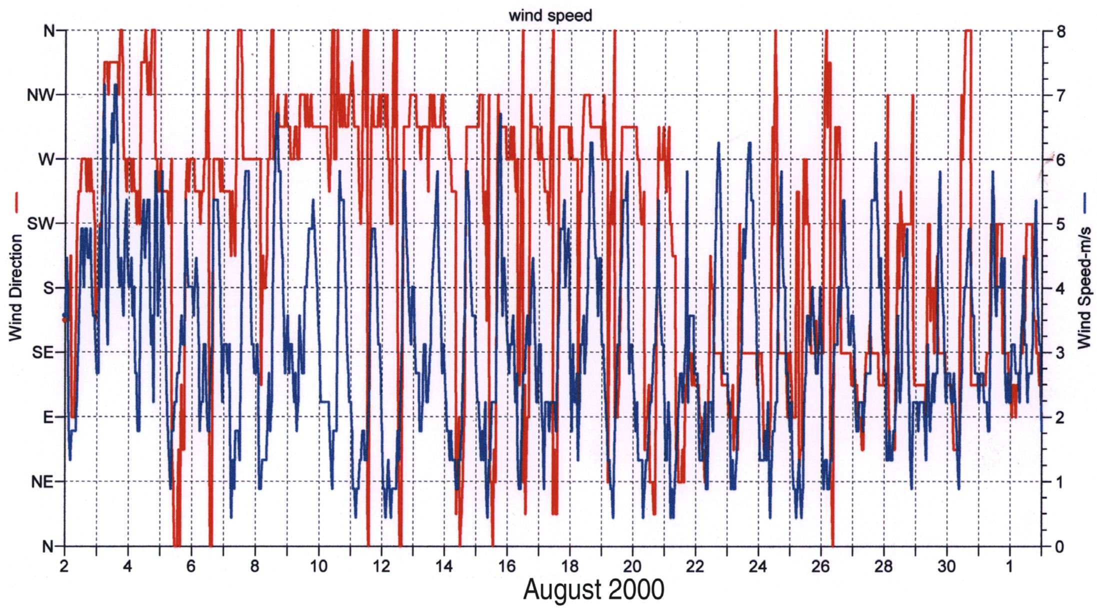


Figure 5.67 Wind Data 2-30 August 2000

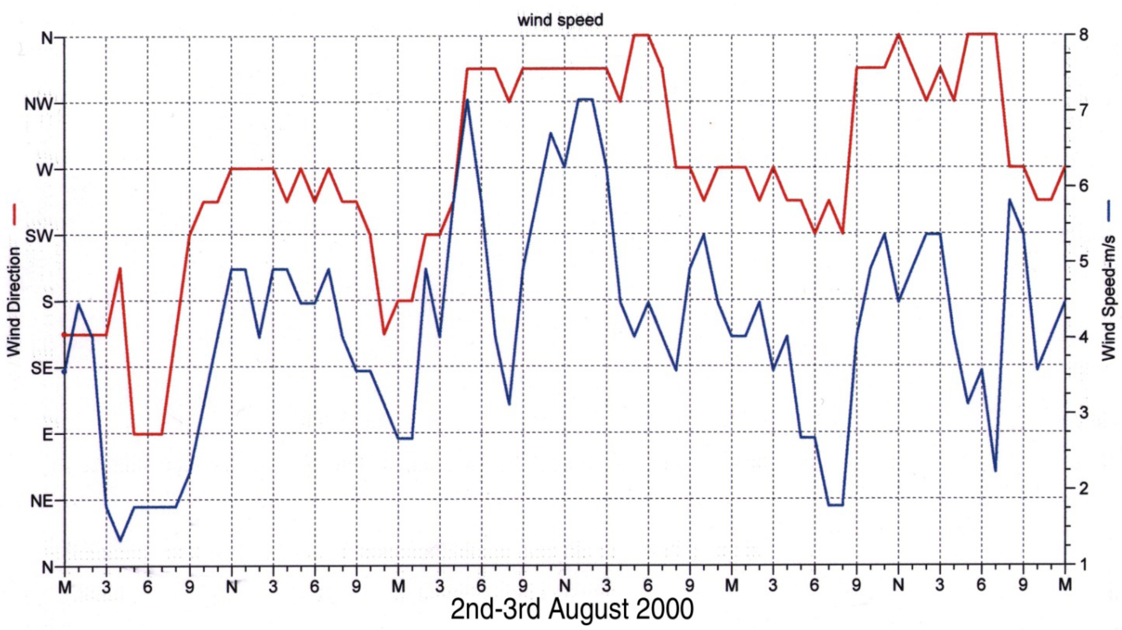


Figure 5.68 Wind Data. 2-4 August 2000

Comparison of the Monitored Data and Ecotect Predictions

Ecotect (Marsch, 1995) performs a 3D model and allows the designer to generate the geometry of a building and then begin simulating and testing its environmental performance. The programme takes all factors into account such as sun penetration, overshadowing, natural and artificial lighting levels, thermal behaviour and acoustic response. Using analytical feedback throughout the design process the programme provides integrated database, which can be used from the most conceptual stages through to final design validation when accurate internal temperatures are needed.

Even though Ecotect can be used as a very quick visualisation tool, it is easy to determine that its primary focus is to substantiate detailed performance and environmental analysis. As a result, it provides functions and descriptive displays such as interactive shadows and reflections, generating overshadowing diagrams, calculating natural and artificial lighting levels, simulating thermal performance, modelling acoustic responses and estimating cost schedules

Ecotect is designed in order to be used at the primary stages of design. This is because it is the best and most efficient way to complete a cost-worthy and energy-saving structure without having to repeat design, or change completed plans. Usually, throughout the use of other software, negligence is noted on the beginning steps of design. This is due to the fact that it was not seen as an important factor to the ecological benefit of construction, as it is impossible to calculate precise figures. However estimates help the designer throughout the entire project bringing him closer to his goal at very early stages, using the know-how through the software to keep in mind all factors and all figures needed. The purpose of monitoring the solar house was comparing the collected data from the data loggers with the Ecotect predictions. Information concerning the buildings was fed into the computer. Then the external conditions were input for all year round, which represents the monitored period for the house. Finally, a simulation was carried out and the Ecotect predictions for certain days were compared with the same days with the measured temperatures. This comparison is presented in the figure 5.69, where the measured external and internal temperatures and the predicted internal temperatures and conditions were plotted.

External Temperatures

Most of the predicted minimum temperatures lie within a zone of 0-9°C around the measured temperature curve for the day. Most predicted maximum temperatures lie within a zone of 1-9°C around the measured temperature curve for the day. This shows that the predicted temperatures are not actually the same as the measured temperatures. In such a case it is seen that the actual monitoring of the house is important. To get the best results, monitoring should be done in a two-year span. In most cases, higher temperature differences are found during the summer indicating that Meteonorm overestimates temperatures during the summer. Proper climatic data should be imported into Ecotect for a better result. This could be taken from the Cyprus meteorological services and transferred into the simulation software. Even the climactic data with the meteorological

station does not agree completely with the temperature of the data loggers. Since the data is a compilation of the mean temperature during 15 years, it is safe to state that every year has it's own individual mean temperature.

Internal Temperatures

Since the external temperatures are not satisfactorily defined then the internal temperatures are also dissatisfying. Although the measured temperatures are satisfactorily in the thermal comfort zone, Ecotect shows the winter months temperatures low, indicating that they are not in the thermal comfort zone. A difference of 0-8 °C between the predicted and measured temperatures is achieved, showing that computer simulation models cannot actually show the actual temperatures in the ESH.

The Ecotect software might be considered as a precise model for the prediction of the temperatures in the different zones. It can be seen, through the graphs, that a daily steady temperature is achieved in the ESH throughout the different zones. All the different zones, which are measured and then compared with Ecotect, show that there is only a slight temperature difference between the zones - up to 2°C

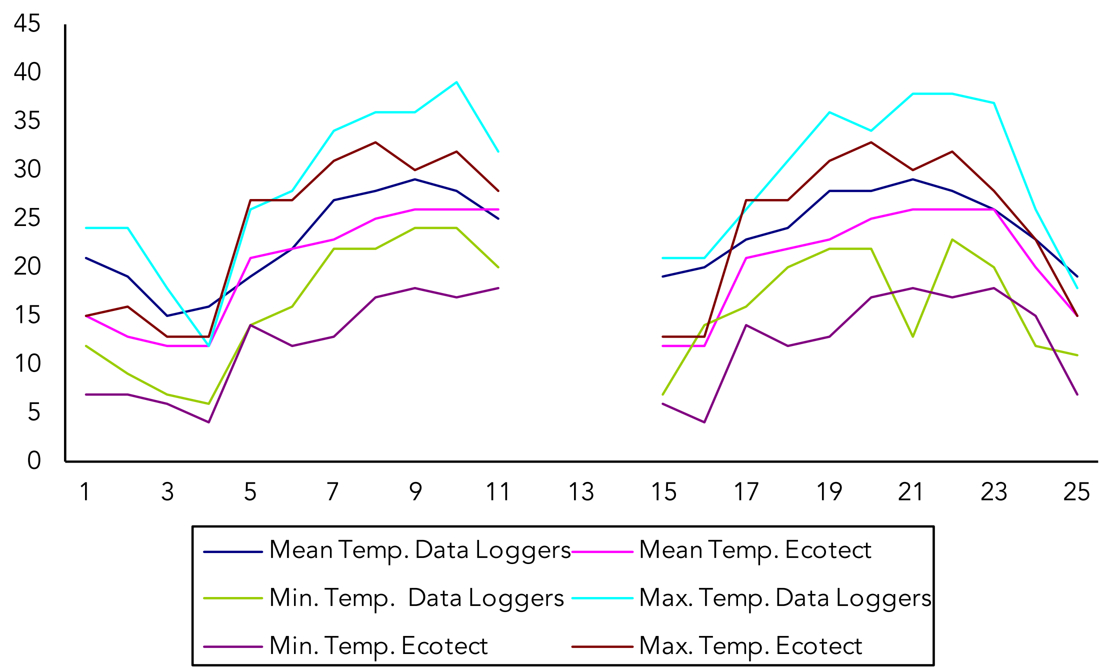


Figure 5.69 Overview Internal and External Temperature differences including monitoring and simulation results

Comparison of the Monitored Results with the Comfort Charts

Measured internal and external temperatures used in the ESH are shown in the previous figures on the data logger's sub-chapter. These measured mean monthly values of temperatures and relative humidity data are shown on Olgyay's comfort chart and the Psychometric chart. The results show the extent to which passive solar energy can cover the heating requirements of the solar house, while natural ventilation or ceiling fans can cover the cooling needs. Internal gains are not taken into consideration.

Olgyay Comfort Chart

The results show that the temperatures and relative humidity data of the solar house are in the thermal comfort areas designed by Olgyay. During the summer months it is shown that ventilation is required, while in the winter months solar energy is required or auxiliary heating.

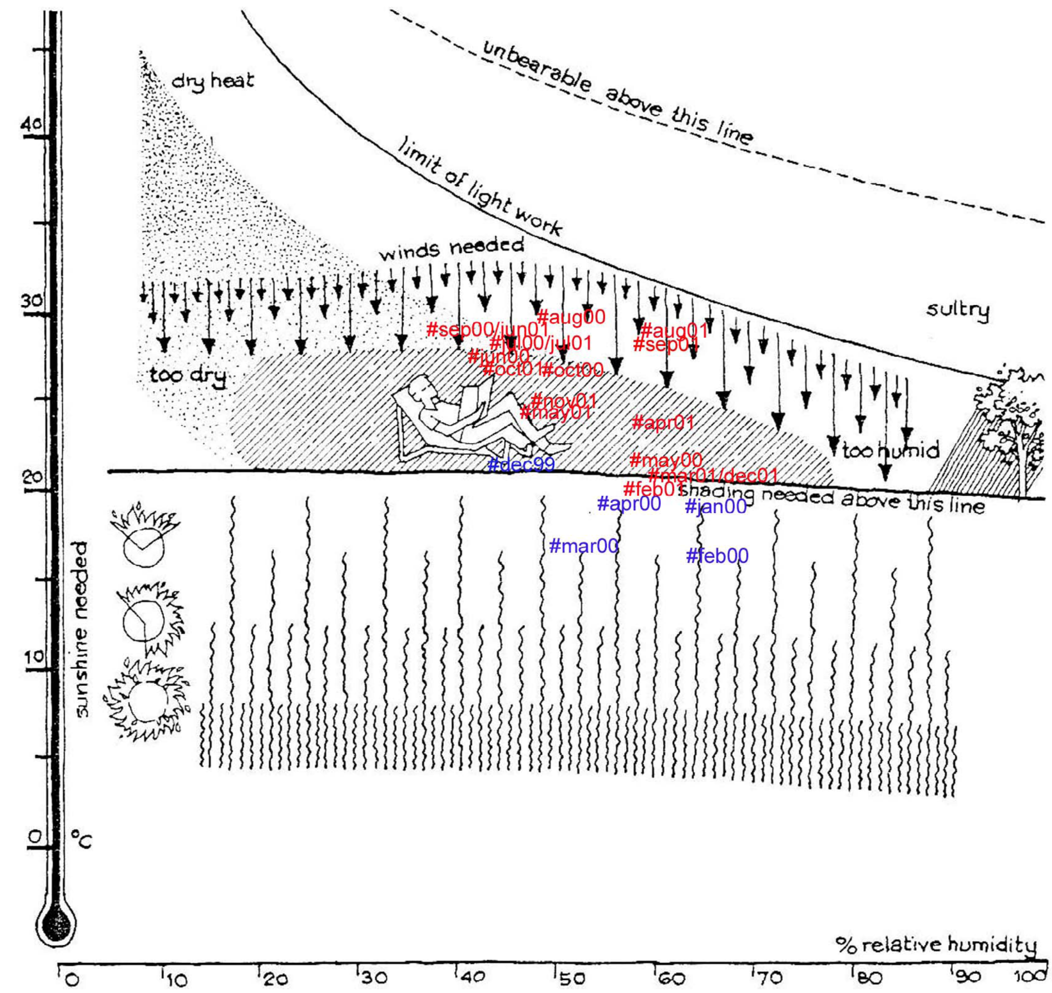


Figure 5.70 Olgyay Comfort Chart with the monitored mean monthly internal temperatures and relative humidity

Psychometric Chart

Figure 5.71 shows a red area at its centre representing the comfort zone. Mean monthly temperature and relative humidity data is plotted as points on the graph, and the relative effects of various passive design techniques on the comfort zone are overlaid. It quickly becomes obvious which systems are the most appropriate for any climate. This information forms the basis of the passive design analysis system. The effects of a range of passive design systems can be overlaid on the chart.

- Red: Comfort Zone
- Pink: Passive Solar Heating
- Light Blue: Thermal Mass Effect
- Dark Blue: Natural Ventilation
- Orange: Indirect Evaporative Cooling
- Light Green: +Night purge Ventilation
- Dark Green: Direct Evaporative Cooling

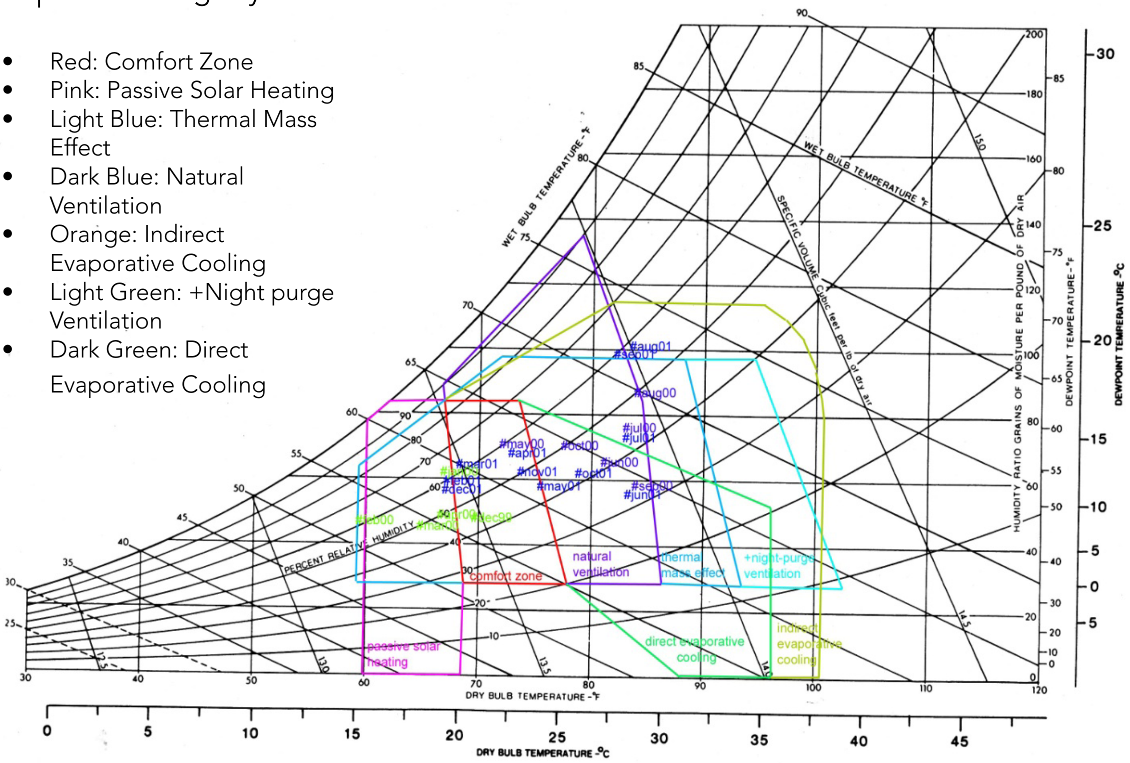


Figure 5.71 Psychometric Chart with the monitored mean monthly internal temperatures and relative humidity

Results of the Comfort Charts

- The best thermal comfort is achieved during the months April, May, October and November. These months need no extra cooling or heating.
- The results show that in order to achieve thermally comfortable conditions, natural ventilation is required in the summer months (June, July, August and September). In this case, natural ventilation actually occurs, or if there are no breezes then the ceiling fans are applied.
- In the months, December (only for the year 2000), January, February and March sunshine is needed (solar heating). It is only 1°C under the thermal comfort zone. This shows that passive solar heating needs to be reconsidered for better efficiency purposes. It must be taken into account that by considering the need for extra

solar heating no over heating shall be achieved in the summer. The same is to be said for the passive cooling needs in the summer. The results certify that all heating requirements are covered through solar energy, while natural ventilation or ceiling fans cover all cooling needs.

- Internal gains are not taken into consideration in our case. Unrealistic assumptions of internal gains can lead to false conclusions about room temperature and comfort.

User Response for the Experimental Solar House

The strong but often subtle relationship between occupant behaviour and how energy is used in a building has been well documented. Virtually every major study conducted on occupant behaviour, as well as the experience of passive solar designers, indicates that the occupants have a positive effect on the energy performance of the solar houses, which cannot and should not be underestimated (International Energy Agency, 1989). Even in the case of non-solar houses, two similar houses can have very different energy usage percentages, depending on the occupant.

The performance of the Experimental Solar House can be evaluated as follows:

- The levels of daylight in the living spaces were very satisfactory.

- Overheating did not occur throughout the whole year.

- Condensation did not occur throughout the whole year.

- Ventilation problems arose sometimes in the summer. This was because there was not a satisfactory amount of breezes during the summer periods. The solution was to operate the ceiling fans at specific times.

- Overheating occurred on a few summer days. The main reason is the lack of shading on the ground floor, since one of the shading devices is vegetation. The trees have not grown enough to provide adequate shade.

- Internal Venetian blinds were placed in the east and west windows. External blinds would have been more efficient. External louvres could have been used but they are extremely expensive.

- To achieve sufficient heating in the bedrooms from the fireplace in the winter the doors of the bedrooms had to be kept open, which results in the lack of privacy of the occupants. For sufficient natural cross ventilation through the clerestory windows of the staircase, again the windows and doors had to be kept open.

- Generally, the occupants responded positively to the heating and temperature levels within the house. The natural lighting levels were regarded as satisfactory and the air quality thought to be very good. The door between the sunspace and the entrance was well used to allow warm air to enter the house.

Experimental Solar House - 15 years after

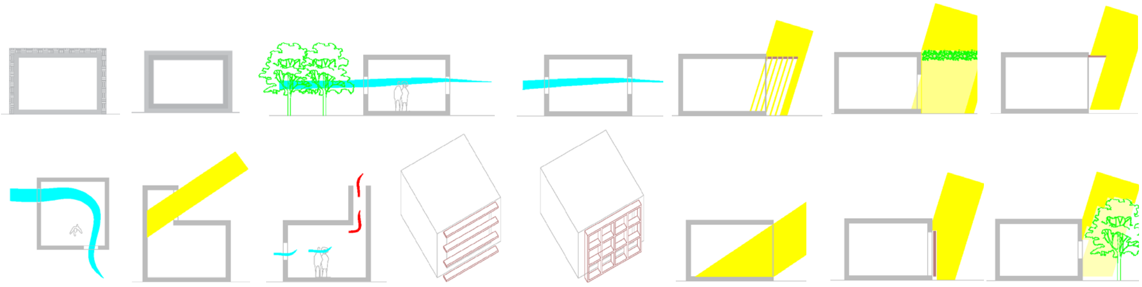


Photo 5.29 South facade, moveable photovoltaic and pond (water storage)

1. Location: Lakatamia, Nicosia District

2. Site: The land is located on a flat area, where neighbouring buildings are located at a distance. On the northern and southern side of the plot are the borders with a green space, while in the west and east the main road is located.

3. Occupants: 2 member family

4. Levels: 2

   - Ground floor: Common spaces. The ground floor is divided into 3 individual spac-

es. One of them being accommodated with the entrance, the living room, dinning area, kitchen and office. The other spaces is the guest room and an office/library. A new bedroom has been created on the northern and eastern side of the house as a guest room.

- First floor: Private spaces (3 bedrooms). The bedroom spaces surround the staircase area.
- Staircase: Situated in a central point with southern clerestory (taking also advantage of direct gain) windows which, when opened contribute to the natural ventilation and stack effect of all the spaces on all the floors.

5. Building structure:

- Building Frame: Reinforced concrete
- Walls: External 25cm masonry brick, 5cm thermal insulation, plaster, stone cladding. The architect has been particularly concerned with the thermal insulation of the shell, both on the outside walls, as well as on the roof and glazing. Two outer walls have been applied with different methods of thermal insulation, of which the most effective bioclimatic one was the layout with external thermal insulation. However, it had aesthetic defects since its heat-insulating material is exposed to the environment and worn (either by environmental conditions or from accidents) very easily.
- Internal walls: 10cm masonry brick wall, plaster, paint.
- Roof: Reinforced concrete, 10cm thermal insulation, water barrier. In addition, on the roof leaving a gap of 60cm from its plate concrete, the thermal insulation of the roof is enhanced.
- Windows: Double glazed, low emissivity, argon filled. Some of the Window frames are wooden, other aluminium and other PVC. The reason was that the owner wanted to experiment these type of windows for the climate of Cyprus.
- Floors: ceramic tiles

6. Bioclimatic approach

- Orientation: most spaces are south orientated
- Thermal mass: floors, walls, staircase
- Passive solar heating: Direct Gain (Glass openings and clerestory windows)
- Solar Control:
    - External Shading Devices: With regards to east and south, the windows were placed more inward thus the external walls were used as external shading.

On the west windows, external shutters were placed since the vegetation had not grown enough to block the summer western sun, as had very effectively worked on the east windows.

- Overhangs: Extension of the pergola at the south side was decided, since the vegetation had been proved not so satisfactory. Especially when the vine had been minimised due to an infection.

- Vegetation: Trees were placed around the building based on the desired conditions the architect wanted to secure. On the eastern side are deciduous trees, which have dense foliage to cut the eastern sun in the summer, while in the winter allow solar radiation to enter. Corresponding treatment also prevails south, with an additional pergola. The trees around the building shell have been developed to a satisfactory level, thus the shading in the summer is fine, while in the winter although the leaves are falling, some branches need to be trimmed so that more direct sun enters the house. The owner prefers the vegetation than extra sun in specific areas.

- Natural Ventilation:

  - Night ventilation (in the summer nights all openings can be opened manually except the clerestory windows which are electrical).

  - Cross ventilation (provisions had been made so that most spaces have openings on two sides).

  - Stack effect (At the top point of the staircase and also at the mezzanine area, clerestory windows have been placed and are opened during the summer months).

7. Non Bioclimatic approach:

- Internal shading devices: Inside moveable blinds where installed to control the solar radiation within the house until the vegetation would fully grow.

- 2 Photovoltaic systems have been installed: 3KW grid connected and 4KW metered.

- The swimming pool filter pump has been changed to a solar pump, so as to minimise the energy demands. The swimming pool pump proved to be high energy consuming.

- 5 water pumps, 3 for the house and 2 for the garden, have been first installed, but later on they were minimised to 2 water pumps- 1 for the house and 1 for the garden

8. Auxiliary heating and cooling

- Central heating-radiators were installed at a later stage (LPG)

- Fireplace (wood)
- Ceiling fans (electricity)

9. Open areas:

- Semi-open areas are created on the southern and northern side via overhangs. The northern semi-open space functions as a parking space, while the southern one is used as a yard.
- Later on a pond was created ($100m^2$). Later on a swimming pool was created ($40m^2$).
- Later on a new building structure was created for the new architectural office of the author, since he decided to move his offices from central Nicosia next to the house, as an independent building.

10. Occupant comments:

- The conditions inside the house during the summer and winter months are ideal. This is mainly due to the insulations in all the building shell avoiding thermal bridges, but also due to the natural ventilation for the summer and direct gain for the winter. The house functioned properly with only a few minutes attention every day, in order to build fires, and operate windows.
- Daytime ventilation (opening of windows and doors) during the summer causes temperatures to rise unsatisfactorily. Therefore signifying the importance of occupant behaviour within the house. Once the pergola and the Venetian blinds were placed, temperatures remained at a considerably steady and comfortable level, thus proving the importance of adequate shading devices, both for the summer and winter.
- To cover heating potential 100%, various thermal storage techniques must be incorporated in order to excuse the lack of thermal mass through carpeting and wall coverings (artwork). Spacings near the ceiling (around clerestory window) should be covered by building transparent coverings in the winter, in order to avoid heat sink.
- Therefore, through all passive techniques, the Experimental Solar House, not only functions successfully, but functions better than the average contemporary house.

Figure 5.78 Site layout

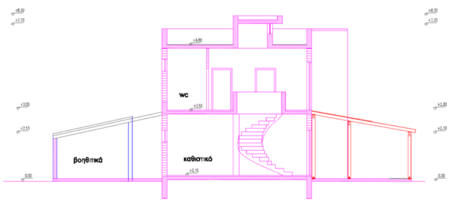


Figure 5.79 East-west cross section through office, living area, and bedrooms

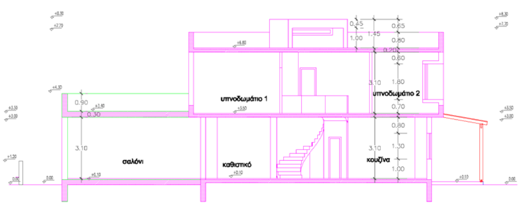


Figure 5.80 South-north cross section through living room and corridors

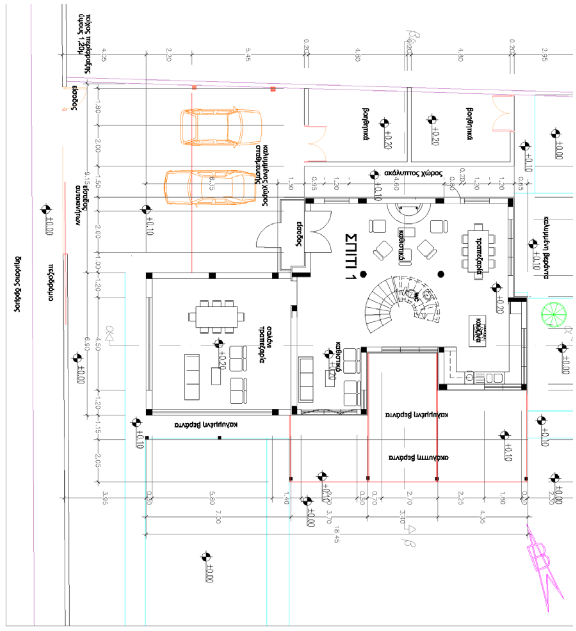


Figure 5.82 Ground floor plan

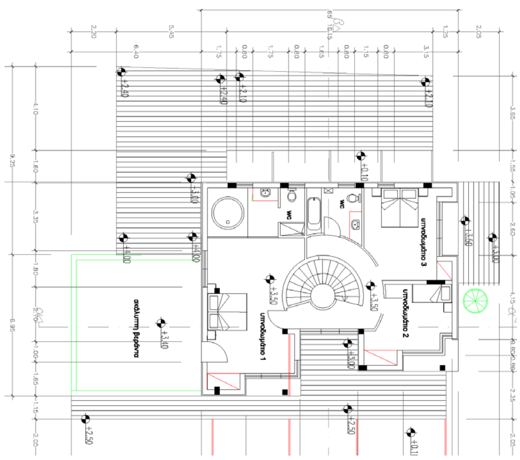


Figure 5.83 First floor plan

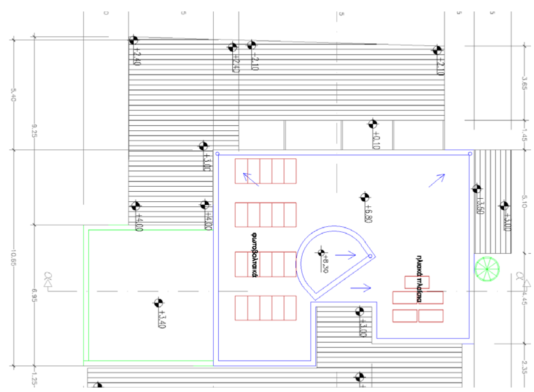


Figure 5.84 Roof plan

Photo 5.30 South and East facade

Photo 5.31 South and west facade

Photo 5.32 South and East facade

Photo 5.34 South facing windows

Photo 5.33 South Veranda shaded by the vines

Utility bills

The only energy used in the Experimental Solar House is electricity, potable water and wood for auxiliary heating. Electricity is required for lighting and cooking. The impressive thermal performance of the house was achieved with only a few minutes of the authors' attention each day: building fires in the cold winters and operating windows in the summer. No adjustments in the author's schedule were required. For this effort, the house rewarded the inhabitants with a low winter and summer utility bill, considering that no air conditioning system is required.

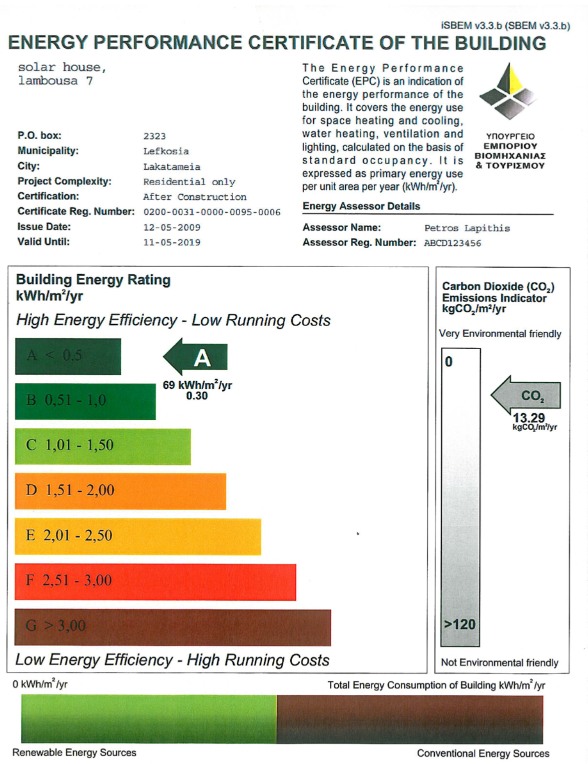


Figure 5.72 Energy performance certificate

Electricity

All the appliances in the house function with an electrical supply of 240V/50Hz. The appliances are: electric oven, electric cooker, dish washer, clothes washing machine clothes dryer, ceiling fans, TV, Hi-Fi system, 5 water pumps (3 for the house and 2 for the garden) and all the lighting features. Electric roof fans were placed in all the spaces. They were used when inside temperatures were above 28°C. Thus, the electric fans consumed some electricity in the summer. The cost was 170€ each. Having an air condition system would cost an overall of €5000 with a high increase in the electricity demand.

At the time of habitation, April 27, 2000, electricity consumption was 320kW/h. 4 months after it was 1542kW/h. The following months it was reduced. The reduction was due to the installation of the grid connected photovoltaic system 0n 5/5/2001 almost at the end of the consumption period. In the summer periods (21/05/-20/09/2001) the consump-

tion was 771kW/h. In the winter period (20/09/2001-19/01/2002) the consumption was 1072kW/h. It can be noticed that the summer period has a lower consumption mainly due to the higher solar radiation and the better efficiency of the photovoltaic system. Other reason for the higher winter consumption is that the author used high wattage electrical heaters for the heating of newborn chicks, which were placed in special cages outside the house. Also in 2006 the house had two new extensions, a guest room and also an office space and in 2013 a new building office in the plot.

It can be concluded that the average monthly electricity consumption of the Experimental Solar House is low, since heating and cooling are not needed. When the photovoltaic system was installed the electricity consumption was reduced by 50%. But when the swimming pool was introduced the consumption rose up to 100% more.

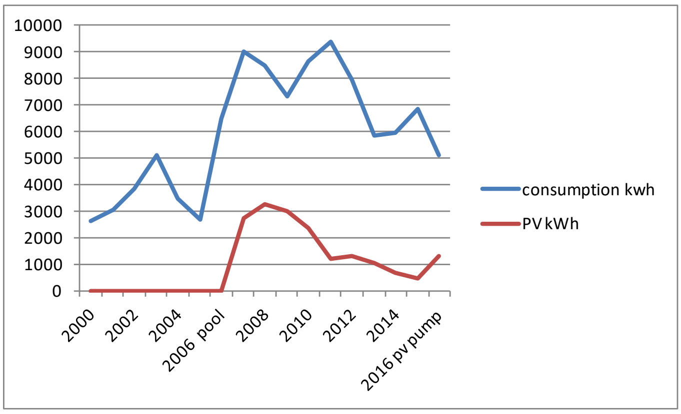


Figure 5.73 Electricity consumption and PV output

Water

The solar hot water collectors provide 100% of the domestic hot-water needs. Provision has been made for hot water to be heated with an electric conductor on the hot water tank. In the case of insufficiency, hot water is available from the solar collectors. During the last two winters, 2000 and 2001, only once was there a need to turn on the electric water heater and that operated for 15 minutes (Energy use of 0.15KW) only.

Water from the water well was used for the watering of the garden and at some point was also used for the toilets and also the swimming pool. A high increase in water can be noticed since the swimming pool was installed and more people were now living in the house.

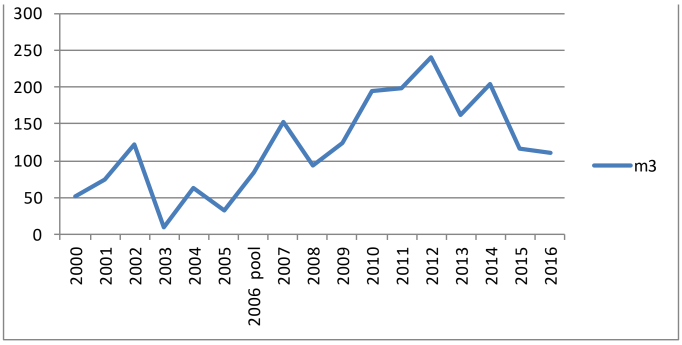


Figure 5.74 Potable water consumption

Wood

The only source of heat is the wood burning fireplace used to warm the ground floor in the evenings when the inside temperatures were under 19.5°C.

A manufacturer-made cast iron wood-burning fireplace was chosen for having an efficiency of 80% (EREC, 2001). A mixture of concrete and plaster was used in order to retain the heat while the fireplace is used. The mixture also acts as a storage heater a few hours after the fireplace has been put out. Small openings are also formed on the concrete plaster so that the cool air of the house passes through the fireplace plaster to be reheated and then circulated back into the house. The correct way of supplying convection air (that is, air that participates in the exchange and distribution of heat) into the heating space (between the fireplace insert and the fireplace casing) provides the inlet grille installed in the base of the fireplace and the two sides of the casing. If it is not always possible to install inlet grilles (filtered air), then the air is sucked into the holes in the base of the fireplace. (Kominki, 2017)

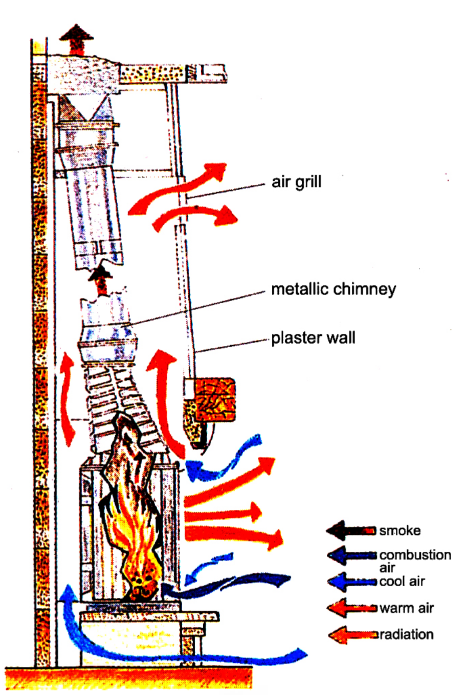


Figure 5.75 Fireplace Installation (Kominki, 2017)

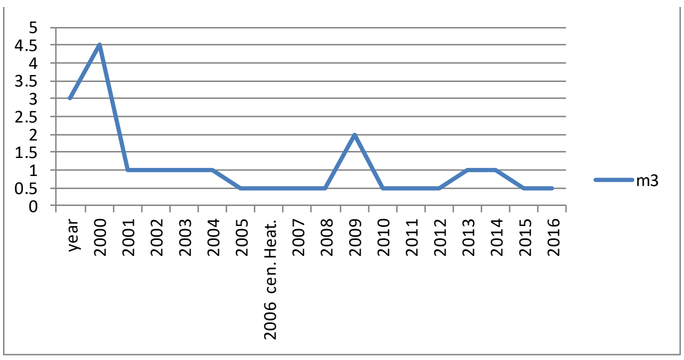


Figure 5.76 Wood consumption

The construction of the fireplace costs €1000. For the central heating system, an extra cost of €4000 is needed, plus €1000 for the piping installation, plus €500 per year for the oil. The boiler and burner of the central heating system has a lifetime of 15 years, while the fire place has a life time guarantee. The piping installation was done provisionally since the author plans to experiment on active solar heating. Another reason that the pipes were installed is that the pipes are placed in the floors and walls.

A full central heating system was thought to be unnecessary because of the type of occupancy, the high insulation standards and the expected solar gains. The fireplace in the open space ground floor therefore provides space heating. These installations were considerably cheaper than full central heating, and the savings made were used partly to offset the extra cost of the other energy saving measures. The energy required for space heating has been reduced to 90% of that required for a standard house.

During the first winter, the author spent 3m^3 of wood and the second winter 4.5m^3. The reason the increase of wood was needed, had nothing to do with thermal comfort but with the psychological factor that the author and visitors enjoyed lighting the fireplace. This proves another positive aspect of the fireplace. It offers a different character to the interior space.

Wood consumption later on was about 0.5-1m^3 per winter. Unfortunately this is not shown in the graphs since the graphs show only the wood that was bought by the author and not the real consumption. The real consumption was not actually measured because at a later stage wood was brought by the author, either from other places or from his own garden since the trees were starting to grow.

LPG

In 2006, the author decided to install the central heating system with an LPG burner. The reason was to experiment and compare further on the energy consumption required to keep steady winter temperatures and later on compare the energy consumption with the energy required for heating a standard house.

It is obvious that the ESH had less energy consumption than a standard house, mainly due to its Bioclimatic design approach such as orientation, passive solar heating, thermal mass and thermal insulation.

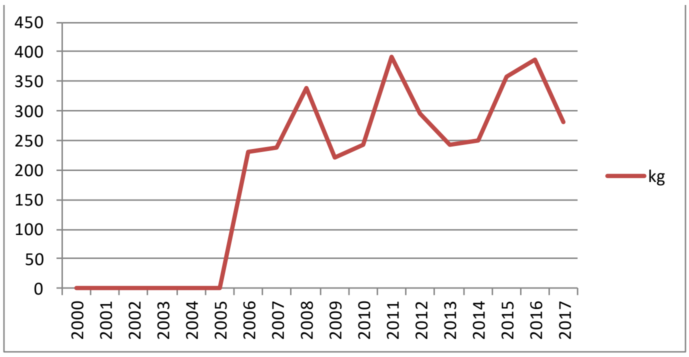


Figure 5.77 LPG consumption for central heating

Conclusion

- The research has demonstrated that it is possible to design low-energy buildings and achieve high thermal comfort at the same time, as well as good indoor air quality, and low environmental impact.

- The research has shown that it is possible to reduce the total energy consumption to a small fraction of the typical consumption. The average total projected energy consumption of the ESH developed in the research is 44 kWh/m^2 per year. This is only about 25% of the typical consumption in residential buildings in Cyprus.

- The total energy consumption does not differ very much from country to country. This is partly because the consumption for water heating, lights, and appliances is relatively independent of climate. The insulation levels are generally low in countries with mild climates and high in countries with cold climates. The energy consumption per square metre, therefore, does not differ as much as one would expect when looking at climatic differences (International Energy Agency, 1997).

- It is necessary to consider the total energy use, and not focus on space and/or water heating alone. It is important to consider both heating and cooling, as focusing on one season could only lead to problems during the other season.

- It is necessary to consider the building as a system, where the different technologies used are integral parts of the whole. The order in which technologies are introduced into the design appears to be quite important. Generally, energy-conservation technologies are considered first, passive solar second, and active solar third.

- High levels of insulation are beneficial in the climatic conditions of Cyprus, as well as in countries where cooling is a major issue.

- Mechanical ventilation systems appear to be essential in low-energy buildings, but their use should be challenged. The solar house uses a form of mechanical ventilation in the ceiling fans.

- Passive solar gains can offer a major contribution to space heating in the climatic conditions of Cyprus and do not lead to overheating if proper solar protection is used. Passive solar cooling also proved to work. In both the heating and the cooling situation, it was necessary to include thermal mass in the direct gain passive solar designs.

- Solar domestic hot water is an effective way to reduce the water heating requirements. Solar heating of domestic hot water was found to be one of the most effective technologies. It is thus used in many buildings in Cyprus. In the ESH, it proved to be the most cost-effective way of further reducing consumption.

- Photovoltaic installations are not presently cost-effective for general use, but PV systems that operate other solar equipment may be efficient. The ESH has grid-connected photovoltaic systems that supply general power. Cost-effectiveness may be

achieved, however, in cases where the system is used to operate solar equipment, such as the swimming pool pump.

- Designing new, innovative building concepts requires a multi-disciplinary design team. It requires the energy aspects to be considered from the early design stage, and also requires the architect, engineer and the clients' collaboration from the beginning.

- Simulation can be reasonably accurate and give a good indication of how the building will perform before it is built. The author used hourly simulation programmes to guide design decisions. Such hourly simulation provided an insight into the building performance, (not otherwise available using more conventional calculation tools). The simulation of building and system performance was also useful for designing the monitoring programs used in evaluating the performance in practice.

- Most energy-consumption figures presented in this chapter are results of these theoretical analyses, as there is only sufficient monitored data from the building. The monitored results available show that the actual energy consumption in almost all cases slightly exceeds predictions. This is partly due to the fact that the user does not behave as expected. The monitored results are therefore somewhat poorer than what is predicted in idealised situations represented on the computer analysis.

- The ESH provided motivation to experiment with new technologies. The author created a group for a very fruitful exchange of ideas. The experiences and the contexts of the participants differ. Therefore, the participants all had something to learn and something to contribute to the development of the ESH presented.

- The ESH has proven that a passive solar construction can indeed maintain steady indoor temperatures, regardless of outdoor conditions. It was also proved empirically that for the solar systems to be successful, the residents must be actively involved in operating the passive solar features.

- Monitoring should be a rigorous and strategic process especially in the part of the individual or individuals in charge of monitoring. It is also apparent that technology plays an integral part in the monitoring of a building. It is also apparent that technology plays an integral part in the monitoring of a building such as the ESH. All the equipment used required an internal battery to function, thus no electricity was used. The single occasion when electricity was required was to run the computer on the day the data was retrieved.

Passive Solar Architecture in Cyprus

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Abstract - The principal element of this research was the design, construction and monitored inhabitation of an Experimental Solar House (ESH) at Lefkosia, taking into account the potential of the well established principles of Passive Solar Design when applied to the specific cultural, economic and climatic contexts of Cyprus. The research into thermal comfort concluded that, for Cyprus, an average 19.5-29°C is an acceptable temperature and an average of 20-75% is the acceptable range of relative humidity. It is concluded that it is impossible to accurately specify final temperatures and RH for the average person, because of the psychological, physiological and practical factors. It is concluded that the passive systems that are most suited for Cyprus are: Direct Gain, external insulation on walls (0.6W/m²K) and roof (0.3W/m²K), low emmisivity double-glazed argon-filled, interior thermal storage constructed from bricks and concrete, 5% north wall openings are sufficient for cross ventilation during summer nights, optimum of south wall openings 18%, permanent external shading devices, vegetation, use of natural ventilation and ceiling fans. Comparative annual energy use of the ESH versus traditional house, contemporary house and a low energy case was performed using computer simulation software Energy 10. The annual energy use of the ESH (121KWh/m²) is less than the contemporary house (368 kWh/m²) and the traditional (243 kWh/m²). Through monitoring the ESH the results show that all heating requirements are satisfied by solar energy, while natural ventilation or ceiling fans meet all the cooling needs, concluding that Passive Solar Design may be successfully applied in the design of modern buildings in Cyprus.

Introduction

This research is set out to demonstrate that passive solar architecture is a viable energy-saving concept that can be applied in the context of Cyprus. A principal aim of the research was to develop an understanding of the criteria for an appropriate passive solar architecture that is sensitive to both energy use and climatic conditions. The Experimental Solar House, supported by this research, is a pioneering project to Cyprus, and shows that passive solar architecture functions in an energy-saving manner is cost-efficient.

In the execution of the research the following parameters were studied:

- The climate of Cyprus
- The comfort zone of the average Cyprus person
- Examples of historical and traditional housing which can be shown to inform passive solar architecture in Cyprus
- The energy uses of the island

The results of these studies show that passive solar design is an appropriate energy-saving strategy for Cyprus. The Experimental Solar House was constructed in order to put the theories developed in the research into practice. Monitoring the Experimental Solar House, led to various conclusions in relation to its performance and to indications for further development and improvement.

This research was fundamentally specified for Cyprus for the following reasons:

- Cyprus has no energy resources of its own. Therefore, more than 94% of the total primary energy is imported to the island of which 15.1% of total annual energy consumption comprises in the residential sector with electricity at 34%, creating not only ecological imbalance but also serious financial government credit.
- Cyprus's climate guarantees 100% energy saving potential and therefore is a suitable starting point for the Experimental Solar House.
- End uses of energy in households are minimized. Water heating from 50% to 0%, space heating from 18% to 0%, lighting 24% from to 0%, cooking 3%, electrical appliances 3%.

Climate of Cyprus

The climate of Cyprus can be summarized as:

- Cyprus is within the Mediterranean temperate zone
- Hot summers rise to an approximate of 41°C in its warmest month
- Mild winters drop to an approximate of 5°C in its coldest month
- Average humidity of 40-60% (sustaining within the comfort zone limits)
- Large daily temperature range (up to 18 °C difference between night and day)

These findings defined the following conclusions, regarding passive solar architecture in Cyprus:

- The large amount of solar radiation which varies from 3.48 KWh/m²day in midwinter to 8.82 KWh/m²day in midsummer, result in the potential for solar energy usage in winter
- Due to the hot summers, passive cooling is needed in Lefkosia

Questionnaire

A questionnaire survey of the satisfaction of Cyprus people living in contemporary buildings was conducted and showed the following:

- Residents felt cold in the winter (80%)
- Residents warm in the summer (87%)
- 64% needed artificial lighting
- 86% experience drafts from windows and doors
- 66% of the residences have no thermal insulation.

It is seen that residents in Cyprus experience many problems due to the climate and conditions of Cyprus. The amount of mechanical cooling and heating used in Cyprus is rising steadily. The best example to follow, as far as non-mechanical cooling and heating is concerned, are those of traditional homes, which were built without the use of energy-consuming devices.

Techniques Used in Historical and Traditional Houses

The following techniques were used in historical and traditional houses, can be used through passive design today and are used for the design of the Experimental Solar House:

- Clear topographical clarifications
- The positions in orientation to the sun path either to avoid direct sunlight entering the building of the opposite.
- The exploitation of breezes for ventilation and cross ventilation in the room
- The awareness and exploitation of the nature of flora and its use for practical functions (e.g. medicinal plants, fruit-baring trees)
- A good insulation of walls (40-50cm width) and roofs,
  The small openings on the external walls for maximum insulation.

These elements can be found in constructions created since 7000B.C. Elements, which are now fundamentally used in passive architecture. Early examples include:

- The Solarium was predominant whether acting as an arched corridor, as a central axis or even when it evolved into a self-contained space.
- Courtyards, planted mostly with deciduous vegetation like grapevines, providing shade in the summer and admitting the sun in the winter
- Almost all openings placed on the south wall providing natural light and heat.
- Arseres (small openings located high on the external walls) allowed lighter hot air to go out of the house and be replaced by cooler air from outside in the summer
- Thymes (small dense bushes) blocked the arseres in the winter and provided thermal insulation.
- Roofs and floors were constructed in a typical insulating manner
- Courtyards were built to facing southwards, acting as a sunspace, receiving desired solar radiation in winter.
- The solarium admitted the rays from the winter sun to penetrate and so solar radiation could be utilized in winter.
- In multiple thermal modes and varied design, the court yard and the solarium moderate high summer temperatures their careful construction combined with the surrounding landscaping lower the temperatures around the building.

These examples, illustrate strong characteristics of historical architecture, which serve as fine examples of energy-saving architecture today and are used on the Experimental Solar House.

Comfort Zone of Cyprus

Using the psychometric chart, Olgyay's bioclimatic chart, Humphreys' comfort chart and Szokolays' equation, specifically adapted for Lefkosia, an average comfort zone was derived for application in Cyprus.
The following conclusions were made concerning thermal comfort in Cyprus:

- Thermal comfort zones depend on regional climate.
- An average of 19.5°C - 29°C is the proposed temperature, within the comfort zone limits of Cyprus
- An average of 20-75% is the proposed relative humidity, within the comfort zone limits of Cyprus.
- The best thermal comfort is achieved in the months of April, May, October and November. These months needed no extra heating or cooling. The results showed that to achieve thermal comfort conditions, ventilation is required in the summer months (June, July, August and September). In this case, natural ventilation actually occurs, or if there are no breezes, then ceiling fans are applied. In the months of December, January, February and March passive solar gains are used to achieve thermal comfort. It must be noted that steps should be taken to avoid over heating in the summer. The results show that all heating requirements are covered through solar energy, while natural ventilation or ceiling fans cover all the cooling needs.

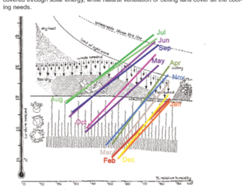


Figure 1. Olgyay Comfort Chart with the monitored mean monthly internal temperatures and relative humidity

The research also concluded that it is impossible to accurately specify final temperatures and relative humidity for the average person, because of the following factors:
Psychological: It is impossible to define a person's psychology within the house indefinitely. For example, although one may be a little cold, a good view of the sun, and a sense of well-being may easily stray the specific individual from seeking heat.
Physiological: It is impossible to define a person's body mass, temperature or amount of clothing he or she may be wearing.
Practical: Passive solar design requires simple passive habits, which cannot be monitored mechanically. It is impossible for example, to be 100% sure that windows will be opened and closed, substantially enough, in order to preserve the required indoor temperature.

Passive Solar Systems for Lefkosia

The development of passive solar systems is significant to the economic, social and political issues raised in this research. The best-known applications of passive solar systems were researched taking into consideration the advantages and disadvantages for Lefkosia were being researched and it is concluded that the passive systems that are most suited for Cyprus and used on the Experimental Solar House, are:
Direct Gain: the simplest solar heating system and can be easiest to build. Areas of glazing not only admit solar radiation for heating but also high levels of daylighting and good visual conditions for the outside. Glazing is well researched and cheap and a material readily available. With adequate insulation of the building, it is possible to rely totally on direct gain as a passive solar system used in the case of Cyprus.
Shape of building: rectangular but compact design (aspect ratio 1:1.33) with the longer axis pointing East and West.
Thermal Insulation: position of insulation externally on walls and roof. Thickness 70mm expanded polystyrene. Overall U-value of walls and roof 0.6 W/m²K.
Thermal Storage (Interior Mass): The simplest heat storage approach is to construct the building of massive structural materials (reinforced concrete or brick blocks) insulated on the exterior, to couple the mass of the indoor space
Glazing: For direct gain systems, south facing window area greater than about 10-12% of floor area require thermal mass, well distributed over floors, walls and ceilings to reduce temperature swings. 5% north wall openings are sufficient for cross ventilation during summer nights. Optimum of south wall openings 40% mountainous areas, 24% coastal region, 18% inland region. Types to be used: Low emmisivity glazing, argon-filled, double-glazed. South vertical glazing surfaces would intercept almost as much radiation during heating season as optimally sloped surfaces. Shading can be easily controlled for the non-heating season.
Solar Control: By use of orientation (one of the long walls is facing south so that the available solar radiation is exploited in the winter), external shading devices, vegetation (shade deciduous trees are excellent for shade in summer while allowing sun through the winter.
Natural Ventilation: By use of cross ventilation, stack effect, night ventilation and ceiling fans.

Construction Decisions

In order to establish the passive solar design targets, construction decisions were required at the design stages of the Experimental Solar House. While considering all aspects of Cyprus's climate, land and market, the following decisions were made.
The high values of solar radiation falling on buildings in summer, and the moderate midday values of solar radiation coming from a clear sky in winter require that: The area of east and west walls was reduced to a minimum. The windows should be placed in south walls and avoided in east and west walls. Small openings are provided in the north walls, mainly for natural ventilation purposes. Windows in the south walls should also be provided with shading devices that provide complete shading from direct solar radiation in summer but do not obstruct the low altitude sun radiation from penetrating building in winter. Solar radiation absorbed by opaque building elements should be reduced to a minimum. The surroundings of buildings should be appropriately treated in order to reduce the values of reflected solar radiation striking the walls.
The high values of outdoor shade air temperatures during summer days, and the low values of these temperatures during winter days, together with the relatively low temperatures during summer and winter night require that: The area of the windows was reduced to a minimum in order to avoid any excessive convective heat gain or loss. Where large windows are required they should be provided with double-glazing, heat-reflecting and absorbing glass, blinds and curtains. The windows be appropriately controlled during the day and night in order to make use of the cool outdoor air during summer night, and to avoid the high outdoor temperature during summer days, and moreover, to increase heat gain from the sun during winter days and limit heat-loss during winter nights.
The high values of both solar radiation and outdoor shade air temperature during the day in summer and most days in winter and the relatively low temperatures at night require that: Opaque building elements be of high thermal capacity and subsequently have an appropriate time-lag and low decrement factor, in order to reduce to a minimum the heat passing through, and in particular to prevent heat emission into buildings during the daytime in summer. Alternatively, if opaque building elements cannot be well insulated in order to obstruct heat from penetrating. The insulation may also be only a cavity.

Upon constructing the Experimental Solar House, it was decided that the house should follow the most suitable combination of design parameters of a contemporary Cypriot home. These are:
Wall construction type: 100x250x300mm brick and 70mm of expanded polystyrene on the exterior, with three layers of plaster on the interior and Adesilex FIS 13 on the exterior sides (U-value 0.296 W/m²k - Type 6), since it effectively insulates the whole structure and avoids thermal bridges where the columns and beams occur.
Roof Type: 150mm concrete, 600mm air gap, 3mm water insulation and 100mm of expanded polystyrene on the exterior, with three layers of plaster on the interior and 50mm on the exterior (U-value - 0.28 W/m²k - Type 3), since it retains heat (thermal mass) and takes advantage of the reverse beam structure of the roof.
External vertical louvers: Not used, as they are not 100% suitable, due to the high construction cost and permanent view obstruction of the east and west facade of the house.
Permanent shading devices: The second floor bedroom windows on the southeast and south walls were recessed to prevent summer sun from entering, but allowing winter warmth to enter.
Extreme overheated periods: Roof fans are used to assure no overheating would occur.

Following the design requirements of a contemporary Cypriot home the house was constructed as thus: concrete frame, floors and roof, brickwork on the exterior and interior walls. The house covered an area of 223m², and was rectangle (1:1.33) in shape.

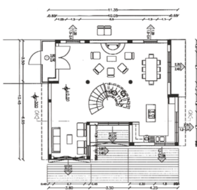


Figure 2. Ground floor plan of the Experimental Solar House.

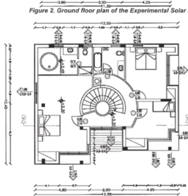


Figure 3. Upper floor plan of the Experimental Solar House.

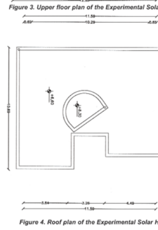


Figure 4. Roof plan of the Experimental Solar House

Monitoring of the Experimental Solar House

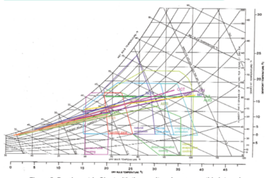


Figure 5. Psychrometric Chart with the monitored mean monthly internal temperatures and relative humidity.

Upon construction of the Experimental Solar House, careful monitoring was pursued, in order to measure its performance in use. Through monitoring the house from the 27/11/1999 until 18/12/2001, using computer data loggers, the following can be concluded:

- The maximum temperature difference between indoor and outdoor temperatures, in the non-habitation period was 10°C
- The maximum temperature difference between indoor and outdoor temperatures, in the inhabitant period was 10-15°C
- The internal temperature and relative humidity throughout the year remained steady (within the thermal comfort limits), despite the instability of external temperatures and humidity percentages.
- Fans needed to be used from the 5th of July till the 20th of August (maximum internal temperature was 31°C).
- Heating needed for 30 days between December and February (minimum internal temperature 17°C). The only source of heating was the fireplace that proved satisfactory.
- Daytime ventilation (opening of windows and doors) during the summer caused indoor temperatures to rise unsatisfactorily (up to 36°C, depending from the external temperatures)
- Once the pergola and the Venetian blinds were installed, temperatures remained at a steady and comfortable level (importance of shading devices)
- The house functioned properly with only a few minutes attention every day, in order to build fires, and operate windows
- Internal relative humidity daily swings were noted at 2-20% (within the comfort zone)
- The Experimental Solar House averages an average energy cost of £26 a month (much lower than that of a contemporary Cypriot house)
- Once the photovoltaic system was installed, this figure reduced to £13 a month.
- The domestic hot water needs were covered 100% by the solar hot water collectors.
- In order to cover cooling potential 100% the pergola and vegetation are necessary
- To cover heating potential 100%, various thermal storage techniques must be incorporated in order to excuse the lack of thermal mass through carpeting and wall coverings (artwork)
- A tent, vegetation or a permanent overhang is more suitable than the pergola, since they would allow shade in the summer, and solar radiation in the winter
- The spacing near the ceiling (around clerestory window) should be covered by building transparent coverings in the winter, in order to avoid a heat sink effect
- It is important to supervise construction closely, in order to ensure design is followed accurately.
- Once thermal mass effects, exposed mass and night purge ventilation, passive solar heating and natural ventilation, comfort percentages rise exceedingly higher than that of a contemporary home.
- The average total projected energy consumption of the experimental building developed in the research is 44 kWh/m2 per year. This is only about 25% of the typical consumption in residential buildings in Cyprus.
- The levels of daylight in the living spaces were very satisfactory.
- Overheating did not occur throughout the whole year.
- Condensation did not occur throughout the whole year

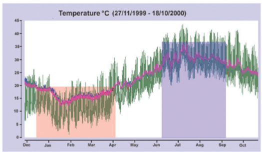


Figure 6. Internal and external monitored temperatures for the year 2000.

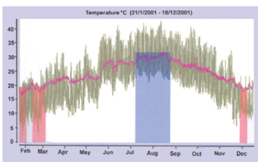


Figure 7. Internal and external monitored temperatures for the year 2001.

Figures 6 and 7 show the heating and cooling needs in the year 2000 and 2001. The dark line shows the internal temperatures throughout the year. Once this line drops below 19.5°C heating is needed (shown in light grey), and once the line rises above 29°C cooling is needed (shown in dark grey). The external temperatures are shown in a lighter black shade. Through these graphs the above results are further enhanced, as a clear distinction is noted between the years. There are moments during the heating and cooling seasons where the fireplace and fans are not needed, as temperatures rise and drop accordingly.

Through monitoring, a few problems, or errors were also noted. These include:
Ventilation problems arose sometimes in the summer. This was because there was insufficient breeze during the summer period. The solution was to operate the ceiling fans at specific times.
Overheating occurred on a few summer days. The main reason is the lack of shading on the ground floor, since one of the shading devices is vegetation. The trees have not grown enough to provide adequate shade.
Internal Venetian blinds were placed in the east and west windows. External blinds would have been more efficient.
The glass door of the entrance broke in the winter and cold draughts were formed through the wooden entrance door. It took two months to replace the glass door.
To achieve sufficient heating in the bedrooms in the winter the doors of the bedrooms have to be kept open, which results in the lack of privacy of the occupants. The same happens in the summer. A grill can be placed on the doors, to allow sufficient natural cross ventilation, and sustaining optic privacy.
The sunspace in the lobby was not entirely successful. In the summer months the sunspace overheated. Fan induced ventilation is needed or the glass door should always be kept open in the summer.
Constructors did not follow accurate design, thus creating problems on matters such as the size of windows. Tight on-site supervision is particularly important in low-energy buildings.

Figure 8. Comparative Barographs Energy - Total annual energy use, plus breakout by heating, cooling, fan, and "other" uses (everything else)

- Contemporary house (368 kWh/m²) versus Traditional (243 kWh/m²)
- Experimental Solar House (121 kWh/m²) versus a low energy case (102 kWh/m²).
- Experimental Solar House (121 kWh/m²) versus contemporary house (368 kWh/m²)

Figure 9. Winter design considerations (north-south section through the staircase)

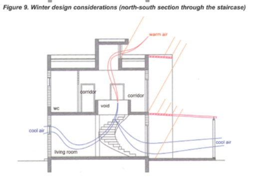


Figure 10. Summer design considerations (north-south section through the staircase)

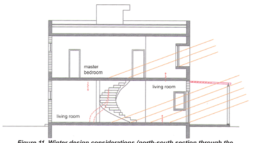


Figure 11. Winter design considerations (north-south section through the master bedroom)

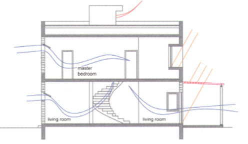


Figure 12. Summer design considerations (north-south section through the master bedroom)

Photo 15. The twin pergola is used for both levels to protect from the southern summer sun. West and south facade

Photo 15. The twin pergola is used for both levels to protect from the southern summer sun. West and south facade

Photo 17. Interior originally painted with warm colours. Later the author decided to re-paint all white to ensure better dispersion of light

Conclusion

Because of Lefkosia's climate, passive solar architecture works to its full capacity. This means that, a passive solar house has 100% energy saving potential.

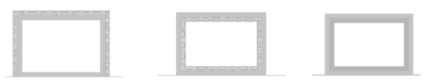
This theory has not remained at its conceptual stage as the Experimental Solar House has demonstrated it in practice.

BUILT PROJECTS

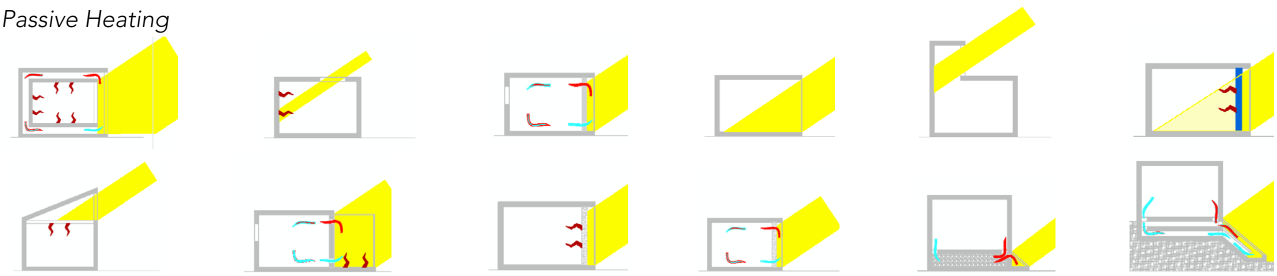
The following built projects have been collected from work done at P.A. Lapithis Architectural Firm. At the beginning of each case study, the local micro-climate was analysed. Each house is briefly described, its key features listed and elaborated on where appropriate. The key lessons learnt are included to enable the reader to benefit from them regarding what to do and not to do, should they wish to emulate the design ideas described in the case studies. The following points are mentioned in all the case studies:

1. Location
2. Site
3. Occupants
4. Levels: Ground floor, First floor, second floor, third floor, mezzanine, attic, Staircase.
5. Building structure: Building Frame, Walls, Internal walls, Roof, Windows:, Floors.
6. Bioclimatic approach: Orientation, Thermal mass, Passive solar heating, Solar Control, Natural Ventilation.
7. Auxiliary heating and cooling
8. Open areas
9. Occupant comments

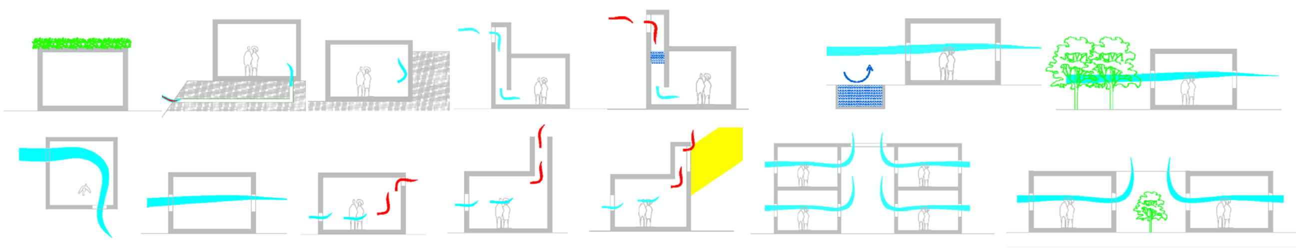
Building Envelope



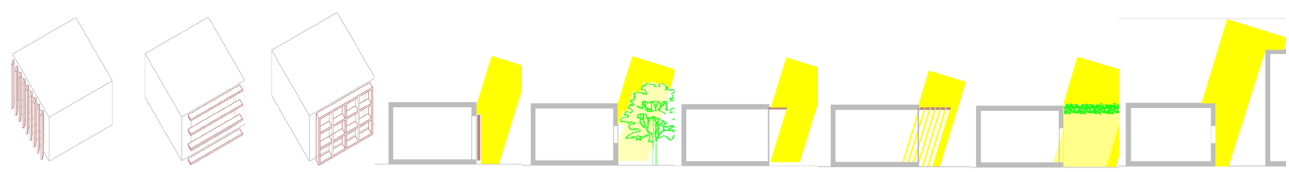
Passive Heating



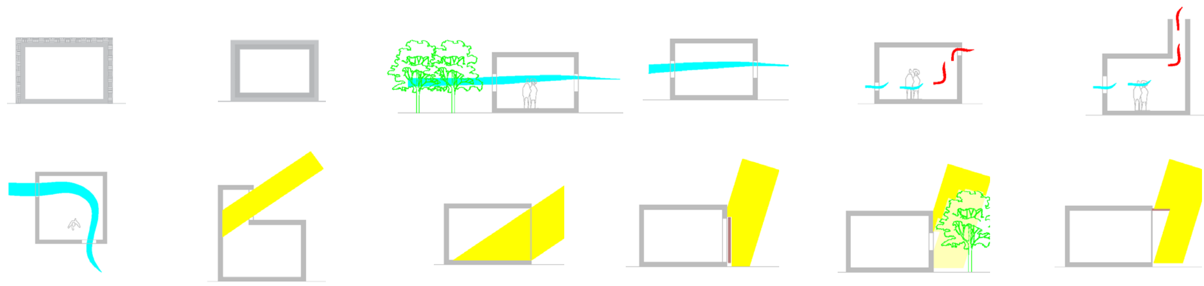
Passive Cooling



Solar Control



House in Oroklini



South facade

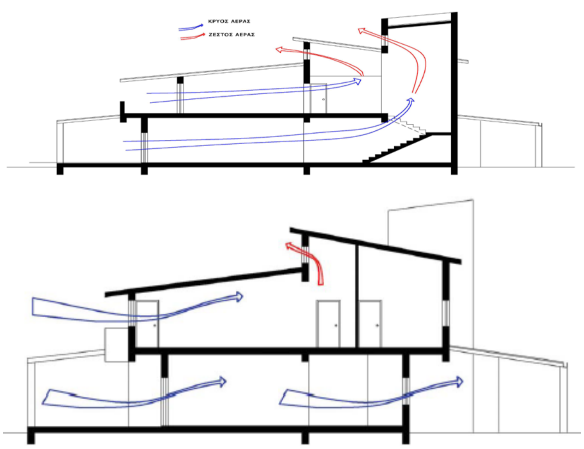
1. Location: Oroklini village, Larnaca District

2. Site: The land is located on a small hill, where neighbouring buildings are located at a distance. On the eastern side there is a road, while in the south, the plot borders a green space - more private.

3. Occupants: Four member family

4. Levels: Three

   - Ground floor: Common spaces. The ground floor is divided into two individual departments. One of them being ac-



South-north cross sections showing the natural ventilation. (Neophytou et al., 2004)

commodated with the entrance, the living room and dinning area. The other department is accommodated with an other living room with dinning area and kitchen (with access to the laundry room).

- First floor: Private spaces (4 bedrooms, office). The bedroom spaces are place surrounding the staircase area. The mezzanine directly communicates with these areas through an internal staircase.

- Mezzanine: office, library, store

- Staircase: The area of the staircase stands out externally due to the super-elevation of its floor, something which the architect intended in order to place clerestory windows. Situated in a central point on the north with southern clerestory (taking also advantage of direct gain) windows which, when opened contribute to the natural ventilation and stack effect of all the spaces on all the floors. On the first floor the bedroom spaces are place surrounding the staircase area and the attic directly communicates with these areas through an internal staircase.

5. Building structure:

- Building Frame: Reinforced concrete

- Walls: External 25cm masonry brick , 5cm thermal insulation, plaster, stone cladding

- Internal walls: 10cm masonry brick wall, plaster, paint

- Roof: Inclined, reinforced concrete, 10cm thermal insulation, water barrier, ceramic roofing tiles

- Windows: Aluminium profile Double glazed, Low emissivity, argon filled

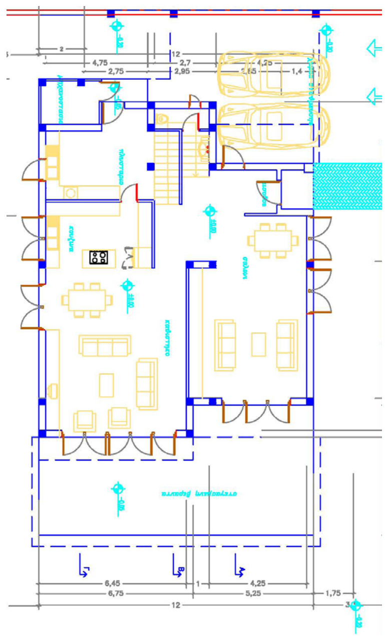
- Floors: ceramic tiles

6. Bioclimatic approach

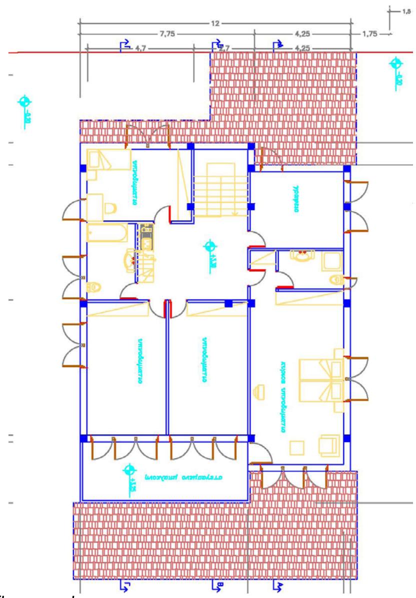
- Orientation: most spaces are south orientated

- Thermal mass: floors, walls, staircase

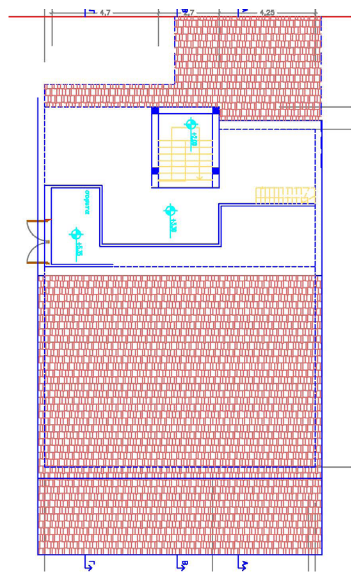
- Passive solar heating: Direct Gain (Glass openings and clerestory windows)



Ground floor plan



First floor plan



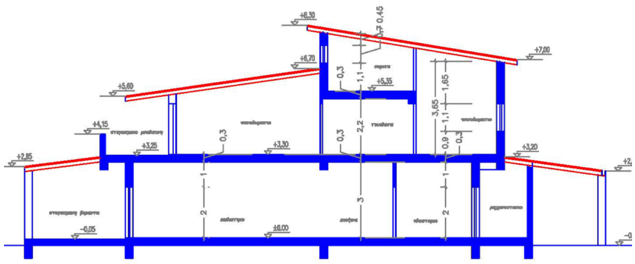
Maisonette floor plan.

South facade

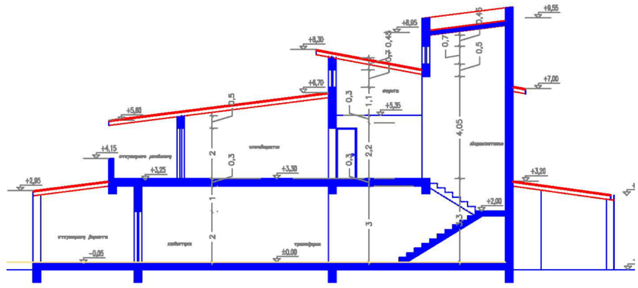
Internal view of the southern clerestory windows and internal balcony (Neophytou et al., 2004).

- Solar Control:
    - External Shading Devices: With regards to east and west external shutters have been placed.
    - Overhangs: The shading of openings is succeeded with the use of overhangs with the extension of the floors on the southern and northern sections and extension of the roof and the balcony on the southern section
    - Vegetation: There is anticipation to plant trees around the building shell, which hasn't developed to a satisfactory level as for yet.
- Natural Ventilation:
    - Night ventilation (in the summer nights all openings can be opened manually except the clerestory windows are electrical).
    - Cross ventilation (provisions had been made so that most spaces have openings on two sides),
    - Stack effect (At the top point of the staircase and also at the mezzanine area, clerestory windows have been placed and are opened during the summer months).

7. Auxiliary heating and cooling
    - Central heating-radiators (petroleum)
    - Split units for heating or cooling (electricity) have been rarely needed
    - Fireplace (wood)
    - Solar water heating
8. Open areas: Semi-open areas are created on the southern and northern side via overhangs. The northern semi-open space functions as a parking space, while the southern one is used as a yard. The open area a mainly covered with grass and trees and the remaining areas are covered with tiling.
9. Occupant comments: The conditions inside the house during the summer and winter months are ideal.

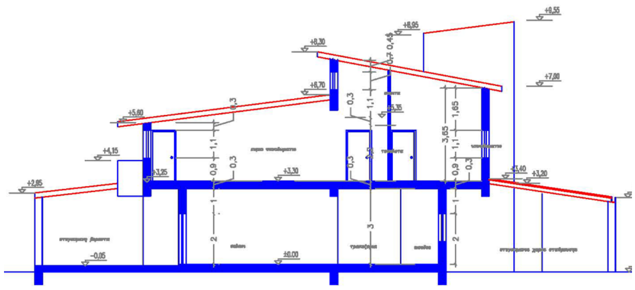


South-north cross section through veranda, living room, kitchen, laundry room, bedrooms, toilet, maisonette



South-north cross section through veranda, living room, staircase, bedroom, maisonette

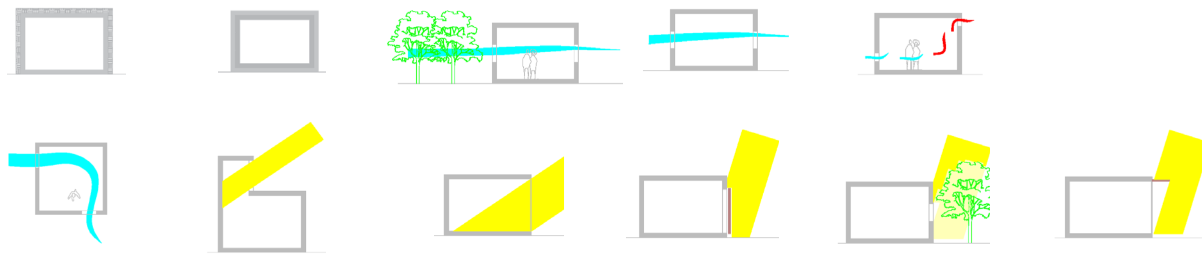
North and east facade



South-north cross section through veranda, living room, master bedroom, office

South and east facade

House in Psematismenos



South facade

1. Location: Psematismenos village, Larnaca District

2. Site: The land is located on a plain, where neighbouring buildings are located at a distance. On the eastern side there is a road, while in the south, east and west the plot borders a green space - more private.

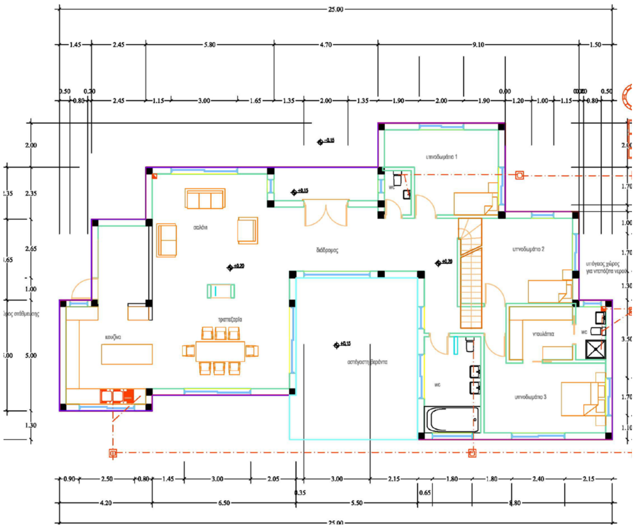
3. Occupants: Four member family

4. Levels: Two

    - Ground floor: The ground floor is divided into two departments, one of

them being accommodated with the entrance and the living room and kitchen in a united space. The other department are the bedroom spaces are place surrounding the staircase area and the attic directly communicates with these areas through an internal staircase.

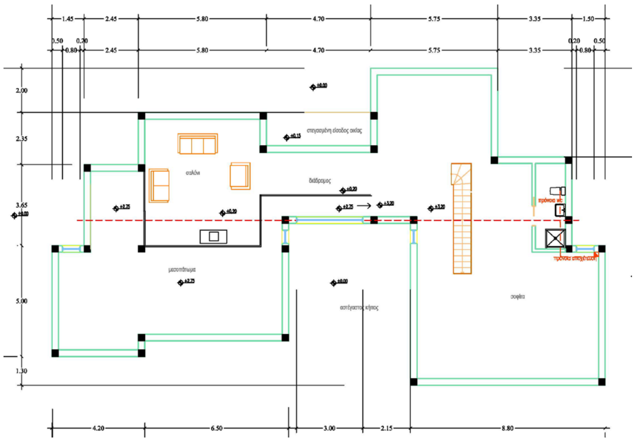
- Mezzanine: office, library, store
- Attic: store
- Staircase: The area of the staircase is hidden something which the architect intended in order to assure the privacy of the top floor



Ground floor plan

5. Building structure:

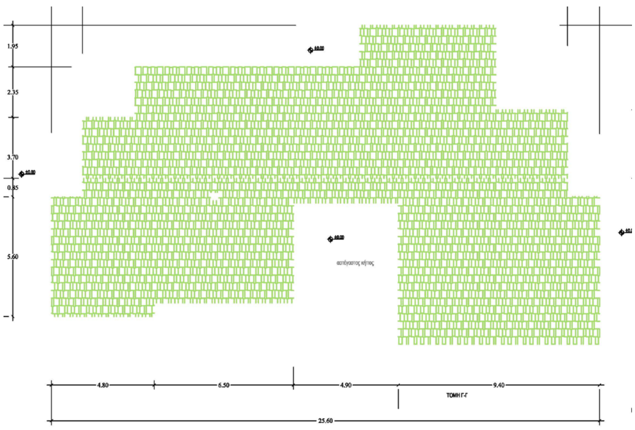
- Building Frame: Reinforced concrete
- Walls: External 25cm masonry brick , 5cm thermal insulation, plaster, stone cladding
- Internal walls: 10cm masonry brick wall, plaster, paint
- Roof: Inclined, reinforced concrete, 10cm thermal insulation, water barrier, ceramic roofing tiles
- Windows: Aluminium, double glazed, Low emissivity, argon filled
- Floors: ceramic tiles



Maisonette and attic floor plan

6. Bioclimatic approach

- Orientation: most spaces are south orientated
- Thermal mass: floors, walls
- Passive solar heating: Direct Gain (Glass openings and clerestory windows)
- Solar Control:
  - Overhangs: The shading of openings is succeeded with the use of overhangs with the extension of the roof on the southern and northern sections. With regards to east and west, the openings are mini-



Roof plan

North and west facade

mum.

- Vegetation: There is anticipation to plant trees around the building shell, which hasn't developed to a satisfactory level as for yet.

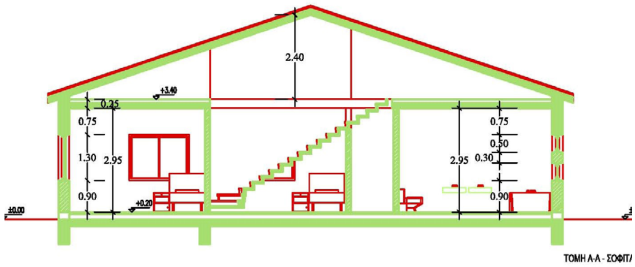
- Natural Ventilation:
    - Night ventilation (in the summer nights all openings can be opened manually.
    - Cross ventilation (provisions had been made so that most spaces have openings on two sides),
    - Stack effect (At the top point at the mezzanine area, and at the attic, windows have been placed and are opened during the summer months).

7. Auxiliary heating and cooling
    - Fireplace (wood)

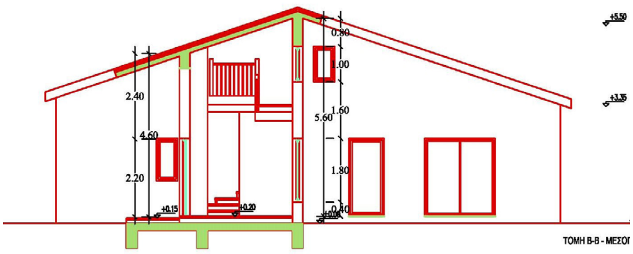
- Ceiling fans
- Solar water heating

8. Open areas: The northern semi-open space functions as the entrance of the house, while the southern one is used as a yard. The open area a mainly covered with vegetation and trees around the building shell, which hasn't developed to a satisfactory level as for yet.

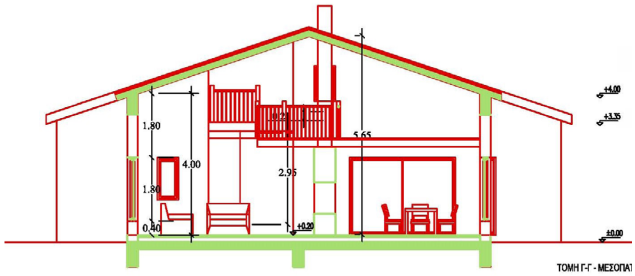
9. Occupant comments: The conditions inside the house during the summer months are ideal.



South-north cross section through bedrooms, staircase, attic



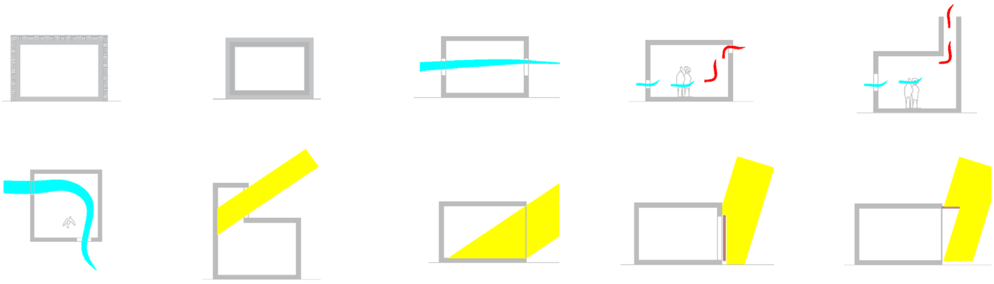
South-north cross section through entrance and maisonette corridor



South-north cross section through living area, dinning area and maisonette

South facade

House in Lakatamia



South facade

South and east facade

1. Location: Lakatamia, Nicosia District

2. Site: The land is located on flat site where neighbouring buildings are located at a distance. On the northern and eastern side there is a road, while in the south the plot borders a open space - more private.

3. Occupants: Eight member family

4. Levels: One

   - Ground floor: The residence is laid out on four parts, in which the daily spaces (sitting

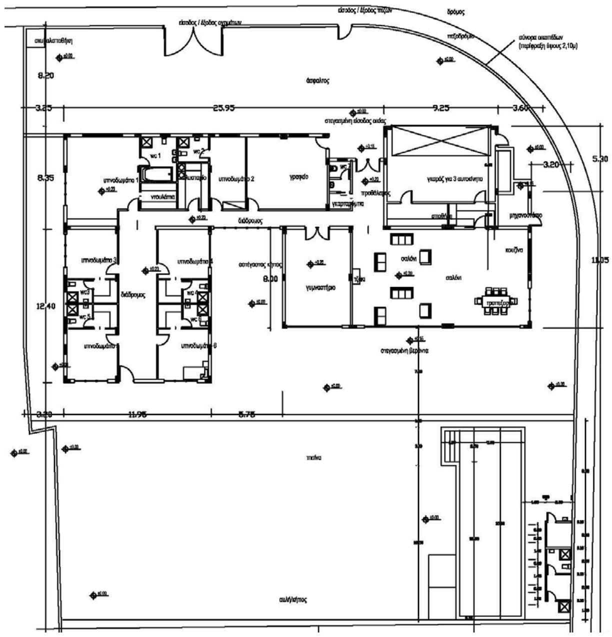
room, living room and kitchen) are situated on the east side, bedrooms are situated on the west side, semi private spaces (office and gym) are found in between. All are oriented on the south. The four part and the northern open space functions as a closed garage and a parking space.

5. Building structure:

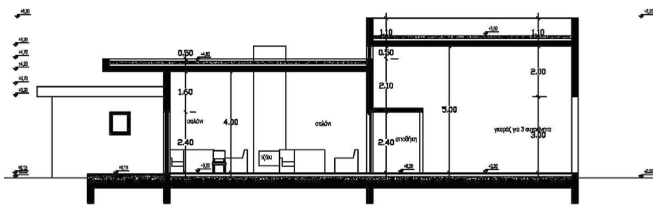
- Building Frame: Reinforced concrete
- Walls: External 25cm masonry brick , 5cm thermal insulation, plaster, paint
- Internal walls: 10cm masonry brick wall, plaster, paint
- Roof: Flat, reinforced concrete, 10cm thermal insulation, water barrier
- Windows: Aluminium, double glazed, Low emissivity, argon filled
- Floors: ceramic tiles

6. Bioclimatic approach

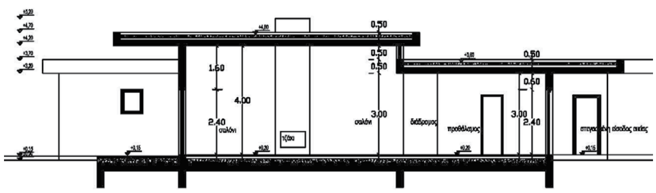
- Orientation: most spaces are south orientated
- Thermal mass: floors, walls
- Passive solar heating: Direct Gain (Glass openings and clerestory windows)
- Solar Control:
    - External Shading Devices: With regards to east and west external shutters have been placed. With regards to east and west, extra moveable overhangs have been provided.



Floor plan and site



South-north cross section through living area and garage



South-north cross section through living area and entrance

North and west facade

- Overhangs: The shading of openings is succeeded with the use of overhangs with the extension of the roof on the southern and northern sections. With regards to south, extra moveable overhangs have been provided.

- Vegetation: There is no anticipation to plant trees around the building shell, which has been proven that there is more sun reflection within the spaces

- Natural Ventilation:

    - Night ventilation (in the summer nights all openings can be opened manually except the clerestory windows are electrical).

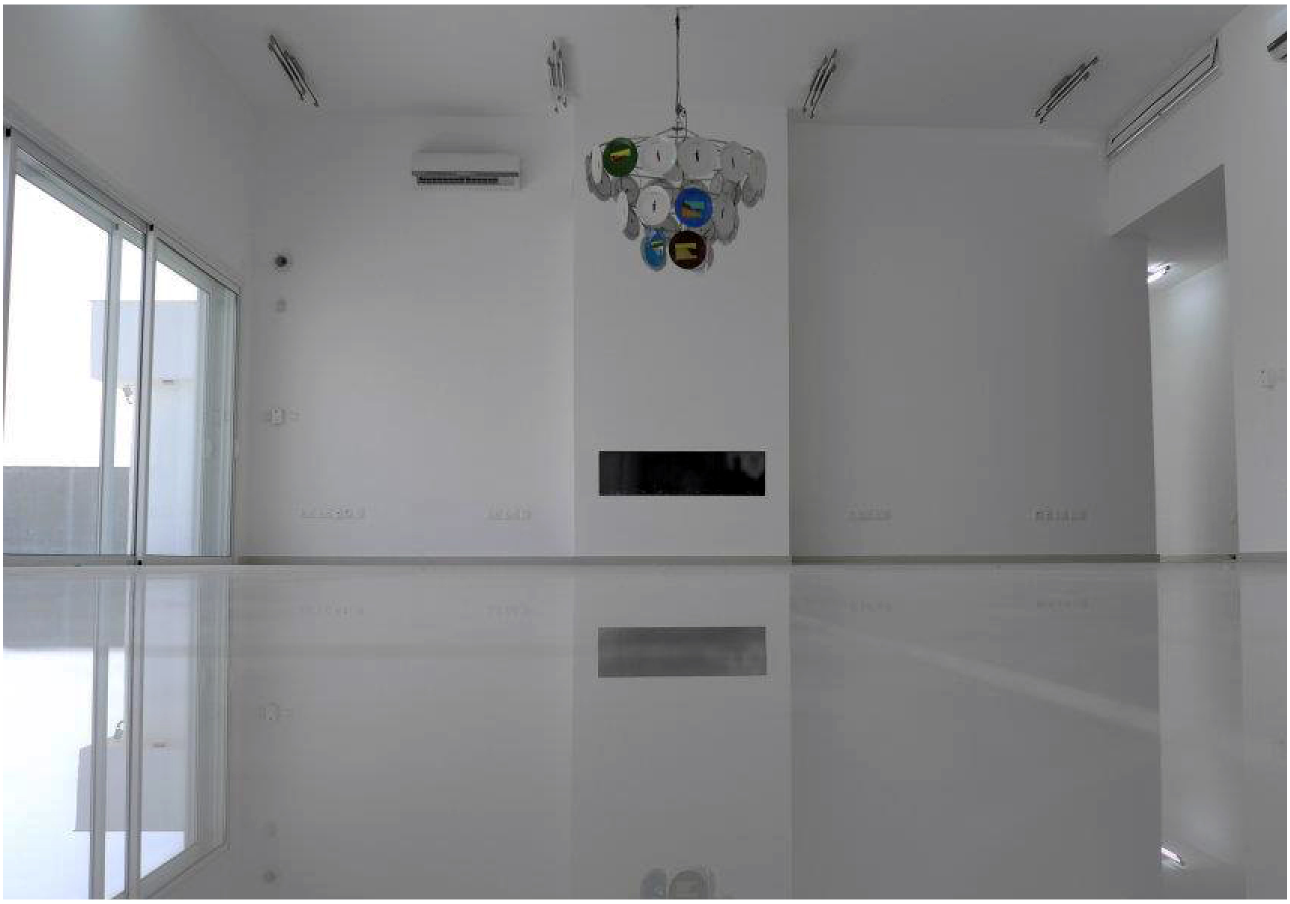
    - Cross ventilation (provisions had been made so that most spaces have openings on two sides),

    - Stack effect: Clerestory windows have been placed at the living room and also at the garage and are opened during the summer months for the warm air to be taken away.

Opening of the living room and the main entrance

South openings at the gym

Living area, south oriented



7. Auxiliary heating and cooling

- Underfloor central heating (solar energy, electricity, geothermal energy).
- Fan coiled units for cooling (geothermal energy and electricity from PV)
- Fireplace (LPG)
- Ceiling fans (electricity)
- Solar water heating (for domestic use and underfloor heating)
- Photovoltaic (both grid connected and net metering)

8. Open areas: Semi-open areas are created on the southern side. The northern semi-open space functions as a parking space, while the southern one is used as a yard. The open area has no vegetation and there is no intention for providing vegetation

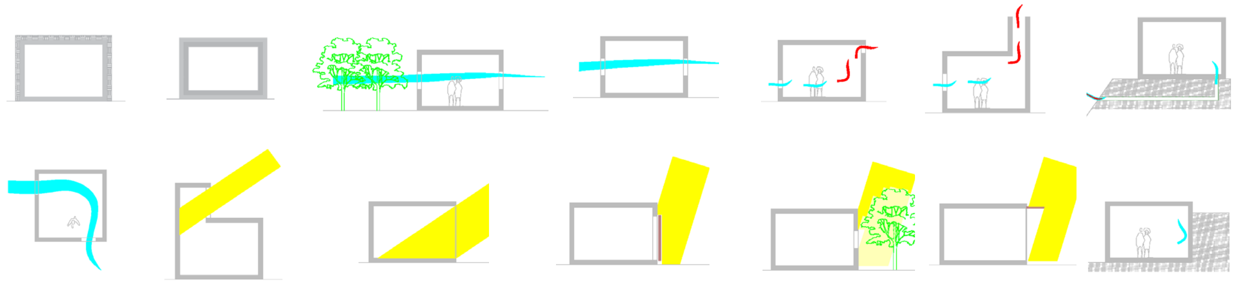
9. Occupant comments: The conditions inside the house during the summer and winter months are ideal. The auxiliary heating and cooling system have been rarely used.

South elevation

South elevation

South elevation

House in Kyperounta



North and west facade (Vasiliades, 2017)

1. Location: Kyperounta village, Limassol District

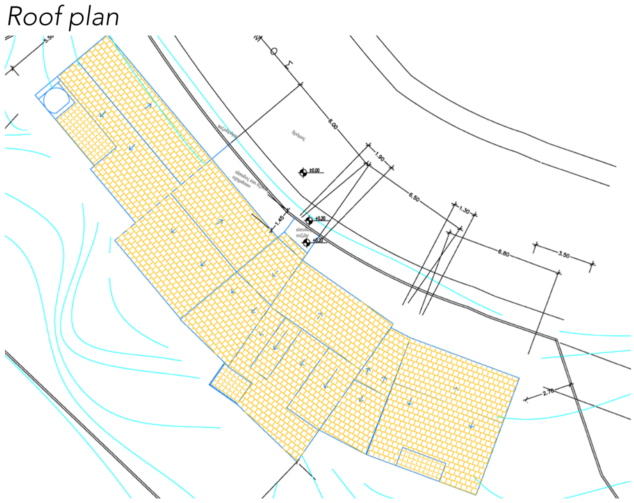
2. Site: The land is located on a mountain, with no neighbouring buildings. On the northern side there is a road, while in the south, west and east the plot borders a forest - more private.

3. Occupants: Four member family

4. Levels: Five

   - Fifth floor: Main entrance, parking, master

Roof plan



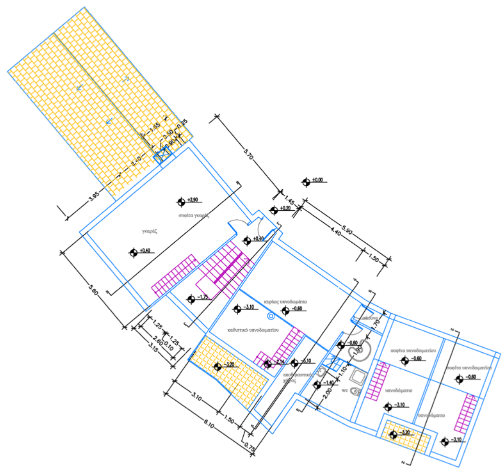
bedroom maisonette

- Fourth floor: Main entrance, parking, master bedroom maisonettes, 2 bedrooms maisonettes
- Third floor: cellar, kitchen, dinning area, 2 bedrooms
- Second floor: living area, store rooms, office, 2 bedrooms
- First floor: store rooms
- Attic: above the garage
- Staircases: Situated in a central point on the north with southern clerestory (taking also advantage of direct gain) windows which, when opened contribute to the natural ventilation and stack effect.

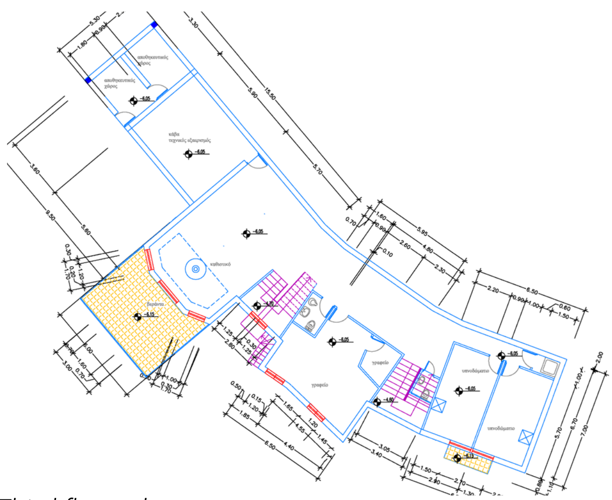
5. Building structure:
   - Building Frame: Reinforced concrete
   - Walls: External 25cm masonry brick , 5cm thermal insulation, plaster, stone cladding
   - Internal walls: 10cm masonry brick wall, plaster, paint
   - Roof: Inclined, reinforced concrete, 10cm thermal insulation, water barrier, ceramic roofing tiles
   - Windows: Double glazed, Low emissivity, argon filled
   - Floors: ceramic tiles

6. Bioclimatic approach
   - Orientation: most spaces are south orientated
   - Thermal mass: floors, walls, staircase
   - Passive solar heating: Direct Gain (Glass openings and clerestory windows)
   - Solar Control:
     - External Shading Devices: none
     - Overhangs: The shading of openings is succeeded with the use of overhangs with the extension of the

Fifth floor plan



Fourth floor plan



Third floor plan

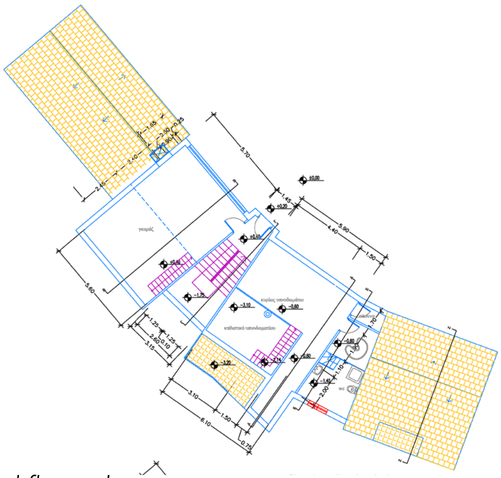
floors on the southern and northern sections and extension of the roof and the balcony on the southern section

- Vegetation: There are existing tall trees around the building shell, which provide a lot of shading in the summer, but unfortunately in the winter also.

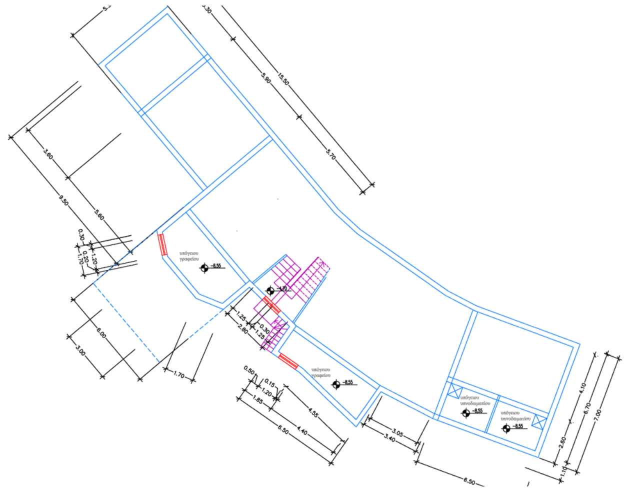
- Natural Ventilation:
    - Night ventilation (in the summer nights all openings can be opened manually except the clerestory windows are electrical).
    - Stack effect (At the top point of the staircase and also at the mezzanine area, clerestory windows have been placed and are opened during the summer months).

7. Auxiliary heating and cooling

- Central heating-radiators (petroleum)
- Fireplace (wood)



Second floor plan

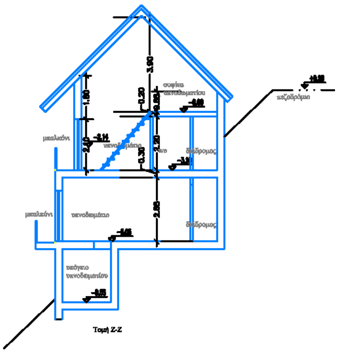


First floor plan

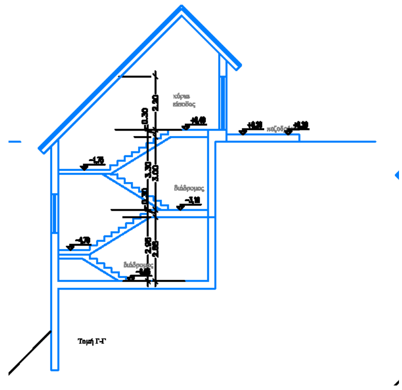
South facade (Vasiliades, 2017)

8. Open areas: The open area is mainly covered with trees.

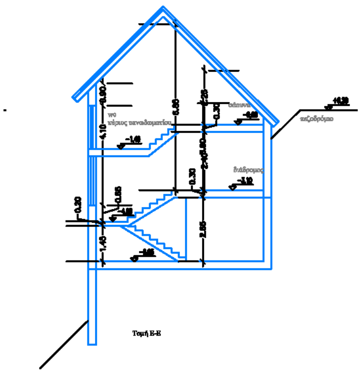
9. Occupant comments: still under construction.



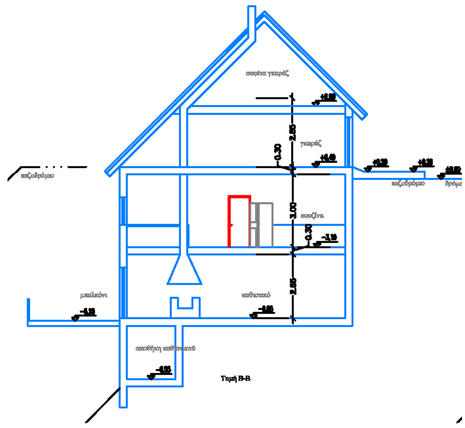
South-north cross section through bedrooms



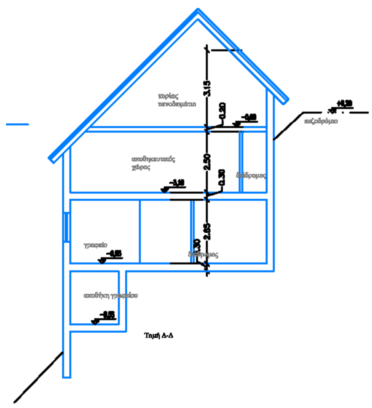
South-north cross section through main entrance and main staircase



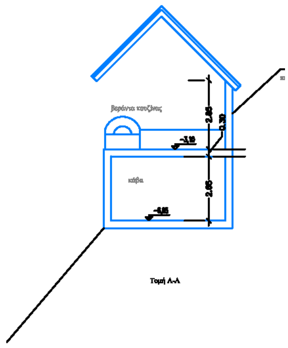
South-north cross section through secondary staircase



South-north cross section through living area, kitchen, garage and attic

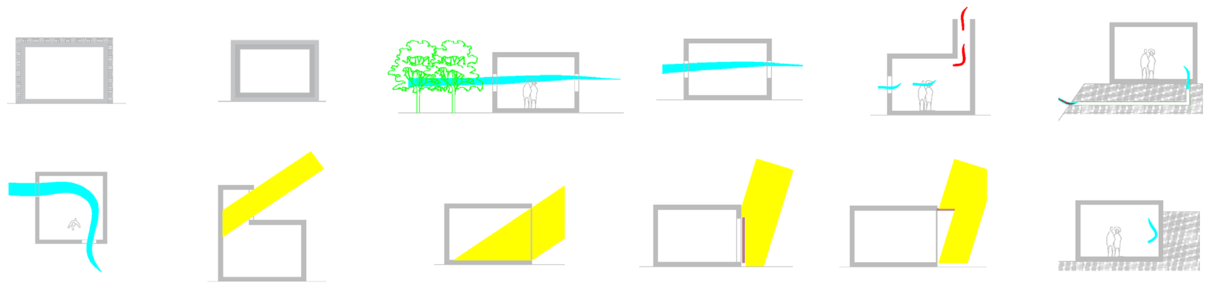


South-north cross section through master bedroom and office



South-north cross section through kitchen veranda and store room

House in Archangelos



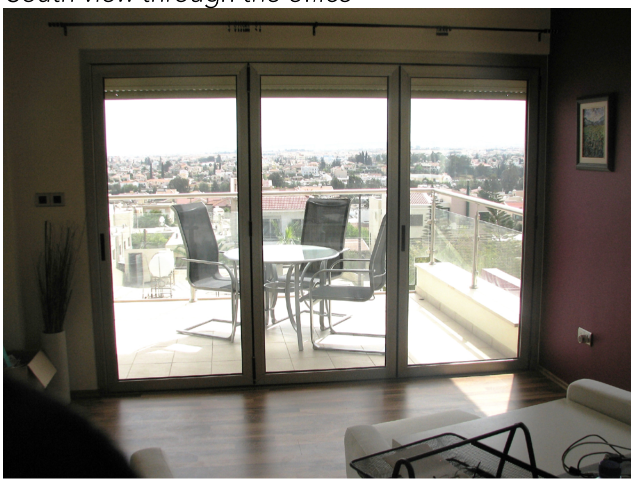
Open space (stack effect)

1. Location: Archangelos area, Nicosia District

2. Site: The land is located on a hill, where neighbouring buildings are located next to the plot. On the north-west side there is a road, while in the southwest the plot borders with an other building

3. Occupants: Three member family

4. Levels: Two. The central idea is based on three parallel zones, which contain independent functions and have a separate approach from the architect. The first and third



South view through the office

zones have similar treatment, as they contain the private character functions and do not communicate inside them directly from floor to floor. The second zone develops on both levels, communicating with each other due to the opening on the floor and containing them shared functions.

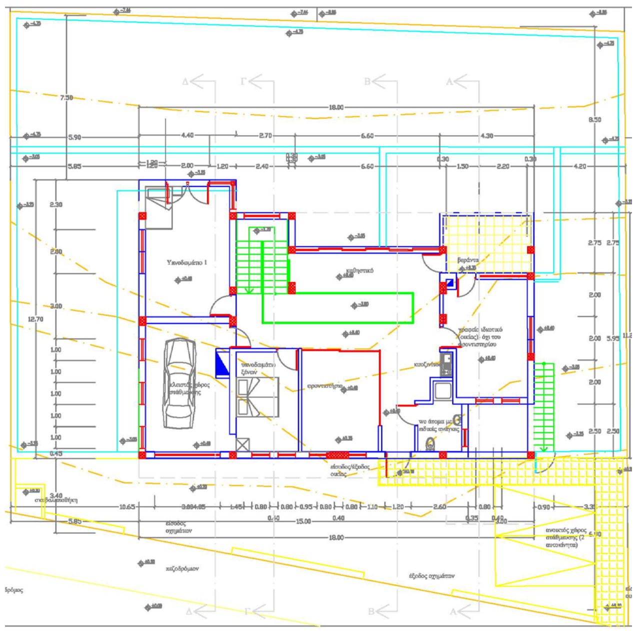
- Ground floor: Private (3 bedrooms) and common spaces (living space, dinning, kitchen -with access to the laundry room).
- First floor: Main entrance of the house, library, office, guest bedroom, garage, small lounge area and the opening in between floors
- Staircase: The central stairway is located in the second zone, along with a lift. The move is channelled each other in the two other zones through it. With regard to the third zone, there is an external staircase which joins through the northern courtyard the two levels together. Situated in a central point on the north with southern clerestory (taking also advantage of direct gain) windows which, when opened contribute to the natural ventilation and stack effect of all the spaces on all the floors. On the first floor the bedroom spaces are place surrounding the staircase area.

5. Building structure:

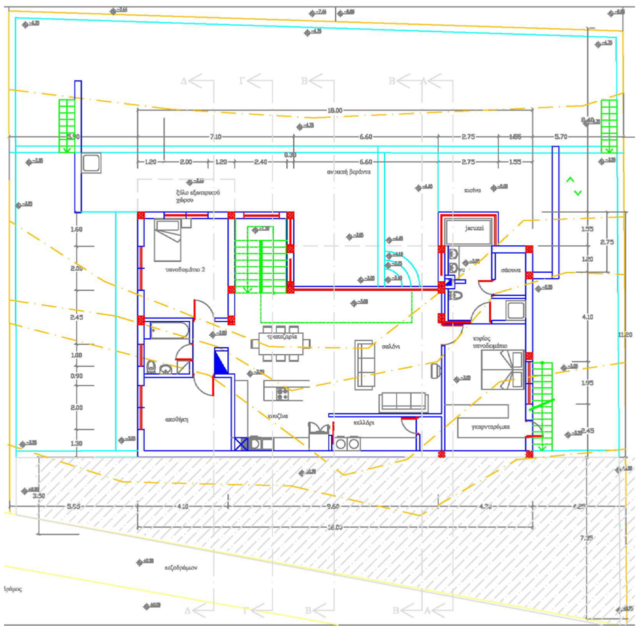
- Building Frame: Reinforced concrete
- Walls: External 25cm masonry brick , 5cm thermal insulation, plaster, paint
- Internal walls: 10cm masonry brick wall, plaster, paint
- Roof: Two types, Flat and Inclined, reinforced concrete, 10cm thermal insulation, water barrier, ceramic roofing tiles
- Windows: Aluminium frame, double glazed, Low emissivity, argon filled
- Floors: ceramic tiles and wooden floor

6. Bioclimatic approach

- Orientation: most spaces are southeast orientated
- Thermal mass: floors, walls.

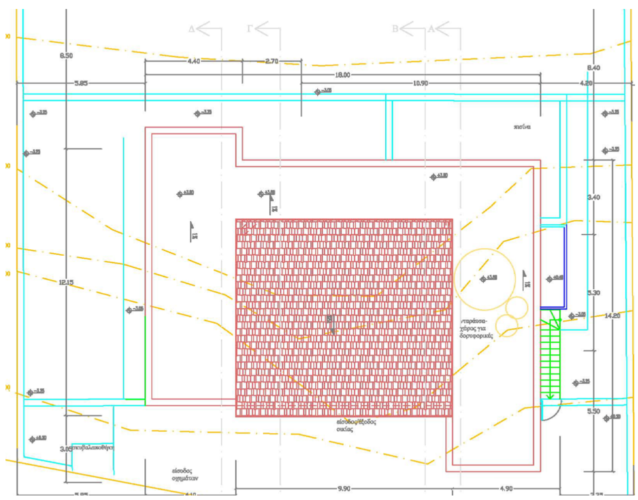


Second floor plan



First floor plan

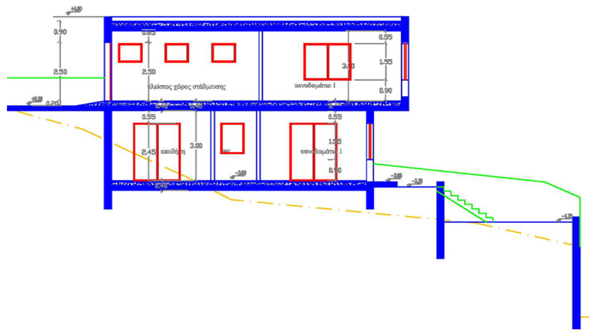
Roof plan



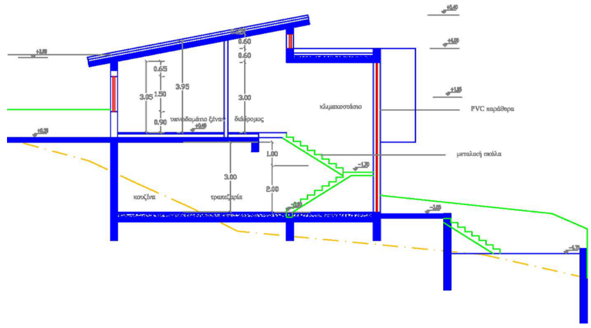
- Passive solar heating: Direct Gain (Glass openings and clerestory windows)
- Solar Control:
    - External Shading Devices: With regards to east and west external shutters have been placed.
    - Overhangs: The shading of the openings is achieved by using a cantilever, extending from the upper floor to the northern part and the roof in the southern part of the plot
    - Vegetation: There is anticipation to plant trees around the building shell, which hasn't developed to a satisfactory level as for yet.
- Natural Ventilation:
    - Night ventilation (in the summer nights all openings can be opened manually except the clerestory windows are electrical).
    - The architect exploiting the altitude differences of the plot, but also the favourable winds, installed an underground pipeline system that introduces the outside air, cooling it, inside. It also enhances the cooling of the building due to its direct contact with the cave terrain.
    - Cross ventilation (provisions had been made so that most spaces have openings on two sides),
    - Stack effect In the second zone of the building volume, through-ventilation is generated throughout the height due to it communication between the two levels. At the same time because of the skylights on the roof, the warm air that trapped inside, escapes outward.

7. Auxiliary heating and cooling

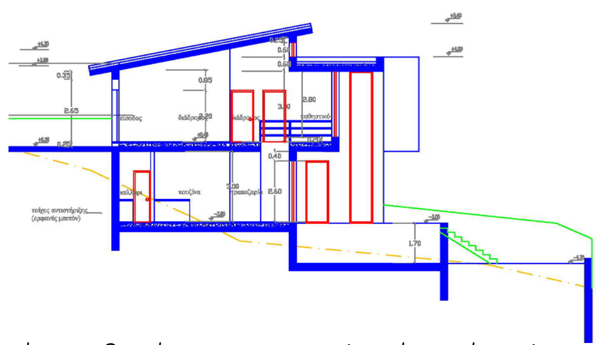
- Underfloor central heating (solar energy, electricity, geothermal energy).
- Fan coiled units for cooling (geothermal energy and electricity from PV)
- Ceiling fans (electricity)



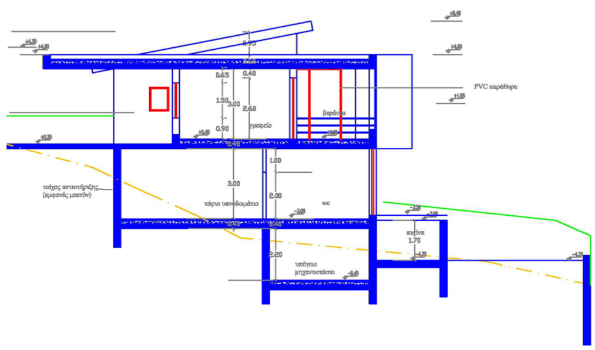
Northwest-Southeast cross section through garage, top bedroom, storeroom, bottom bedroom



Northwest-Southeast cross section through library, staircase, kitchen and dinning space



Northwest-Southeast cross section through main entrance, living room, swimming pool



Northwest-Southeast cross section through office, balcony, main bedroom, swimming pool, mechanical room

- Solar water heating (for domestic use and underfloor heating)
- Photovoltaic (both grid connected and net metering)

8. Open areas: The open-air area extends around the house, divided into two sections through walls, in private and shared. The section of the northern courtyard in front of the office space functions as semi-open space if housed through cantilever. The existence of a water element in the south and planting in the southern, eastern and western parts of the improve the micro-climatic conditions around the shell. Semi-open areas are created on the southern and northern side via overhangs. The northern semi-open space functions as a parking space, while the southern one is used as a yard. The open area a mainly covered with grass and trees and the remaining areas are covered with tiling.

9. Occupant comments: The conditions inside the house during the summer and winter months are ideal.

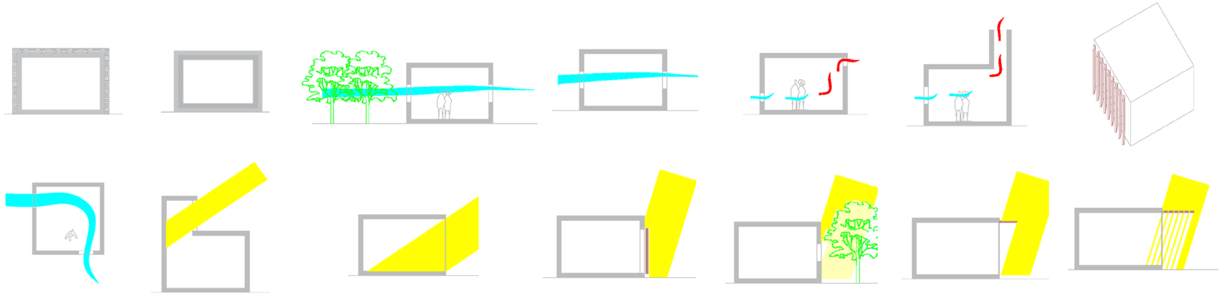
Kitchen, dinning and living area

Living area and southeast openings.

Main staircase

Open space (stack effect)

House in Agios Andreas



South and west facade

Original South and west facade

1. Location: Agios Andreas area, Nicosia District
2. Site: The building is located in a downtown neighbourhood, where the architect acted on an existing shell. In the south there is the road and opposite existing residential buildings. The eastern boundary of the plot is adjacent to a neighbouring building while the north and west are free.
3. Occupants: Eight member family
4. Levels: Three

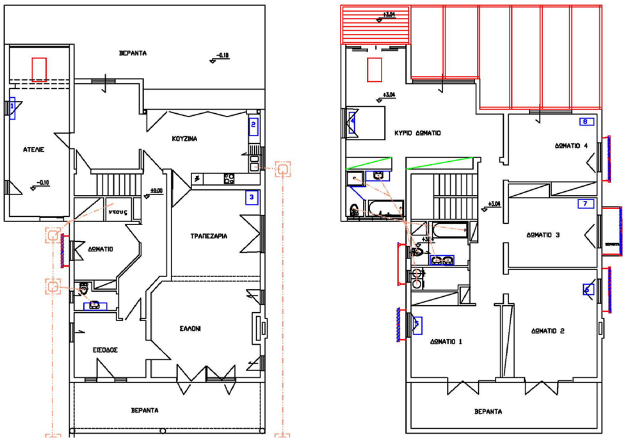
- Ground floor: Common spaces (lounge - kitchen - dining room) are located on the ground floor. Before the renovation the rooms were separated by internal walls. The place that used to be the old kitchen has now become unified along with the rest of the living room and the kitchen has been moved to a bay which once functioned as an atelier. On the ground floor there is a closed corridor, which leads to the bedrooms for the privacy of the tenants.
- First floor: Private spaces (5 bedrooms). are placed surrounding the staircase area.
- Second floor: bedroom, roof veranda
- Staircase: Situated in a central point on the west side with clerestory (taking also advantage of direct gain) windows which, when opened contribute to the natural ventilation and stack effect of all the spaces on all the floors.

5. Building structure:

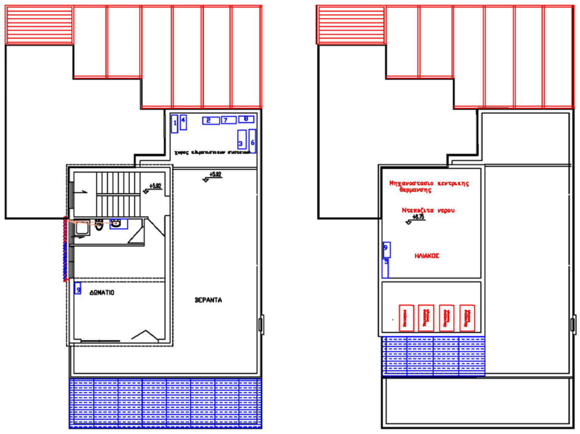
- Building Frame: Reinforced concrete
- Walls: External 20cm masonry brick , 5cm thermal insulation, plaster, paint
- Internal walls: 10cm masonry brick wall, plaster, paint
- Roof: Reinforced concrete, 10cm thermal insulation, water barrier, ceramic tiles
- Windows: Wooden framed, double glazed, Low emissivity, argon filled
- Floors: ceramic tiles and timber flooring

6. Bioclimatic approach

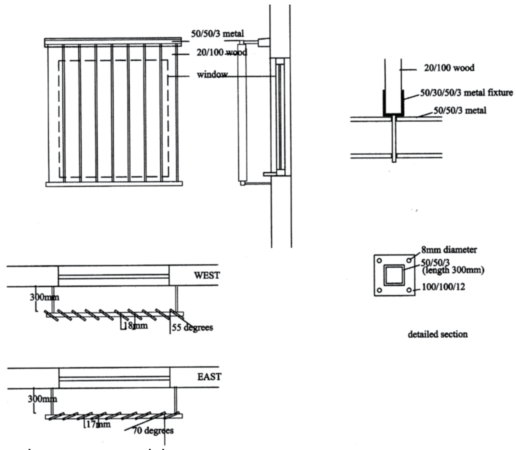
- Orientation: most spaces are south orientated
- Thermal mass: floors, walls
- Passive solar heating: Direct Gain (Glass openings)
- Solar Control:
    - External Shading Devices: On the south openings aluminium horizontal louvres that are designed in such



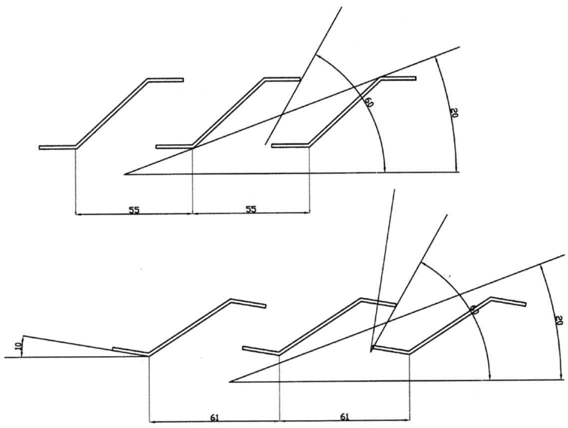
Ground floor and first floor plans



Second floor and third floor plans



Wooden vertical louvres



Aluminium pergola

a way that the winter sun is allowed to pass and the summer sun is excluded. For the east and west openings vertical wooden louvres were designed, so as to avoid the eastern and western low summer sun, while letting the summer night breeze to pass through.

- In the private courtyard where the pool is located, there is a pergola over the large opening allowing the living area to communicate directly with the outside.

- Overhangs: The shading of openings is succeeded with the use of overhangs with the extension of the floors on the southern and northern sections and extension of the roof and the balcony on the southern section.

- Vegetation: There are trees around the building shell, which have developed to a satisfactory level.

- Natural Ventilation:

  - Night ventilation (in the summer nights all openings can be opened manually)

  - Cross ventilation (provisions had been made so that most spaces have openings on two sides).

Original Living area

Living and dinning area

Living area

Open area with an indoor view

- Stack effect (At the top point of the staircase area, clerestory windows have been placed and are opened during the summer months).

7. Auxiliary heating and cooling

- Central heating-radiators (petroleum)
- Split units for heating or cooling (electricity) have been rarely needed
- Two fireplaces (wood)
- Ceiling fans

8. Open areas: Semi-open areas are created on the southern and northern side via overhangs. The northern semi-open space functions as a parking space, while the southern one is used as a yard. The open area is mainly covered with trees.

9. Occupant comments: The conditions inside the house during the summer months are ideal.

Video Existing Building: https://www.youtube.com/watch?v=3NQKykhYfIk

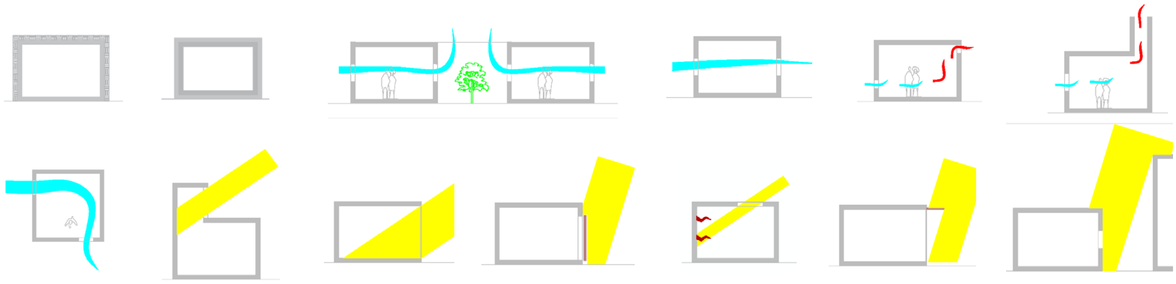
Original House: south and west facade

West facade

Original north facade

Open area, east and north facade

House in Vavla



Semi-open space and courtyard

Original semi-open space and courtyard

1. Location: Vavla village, Larnaca District

2. Site: The house is located in the centre of the village, where neighbouring buildings are attached on all sides of the building, except a small part where the external entrance door is located

3. Occupants: Three member family

4. Levels: One and Two

- Ground floor: The ground floor is divided into two individual departments. One of

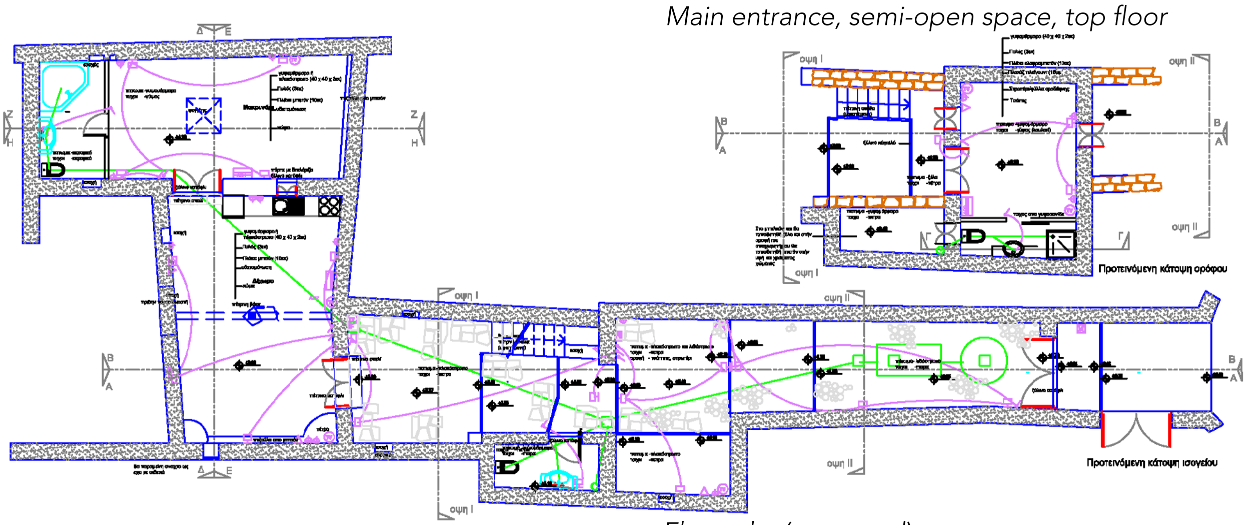
them being accommodated with the entrance, the living room, dinning area and kitchen. The other department is accommodated with 2 bedrooms.

- First floor: 1 bedroom with an independent entrance and Staircase situated externally and communicates with the courtyard.

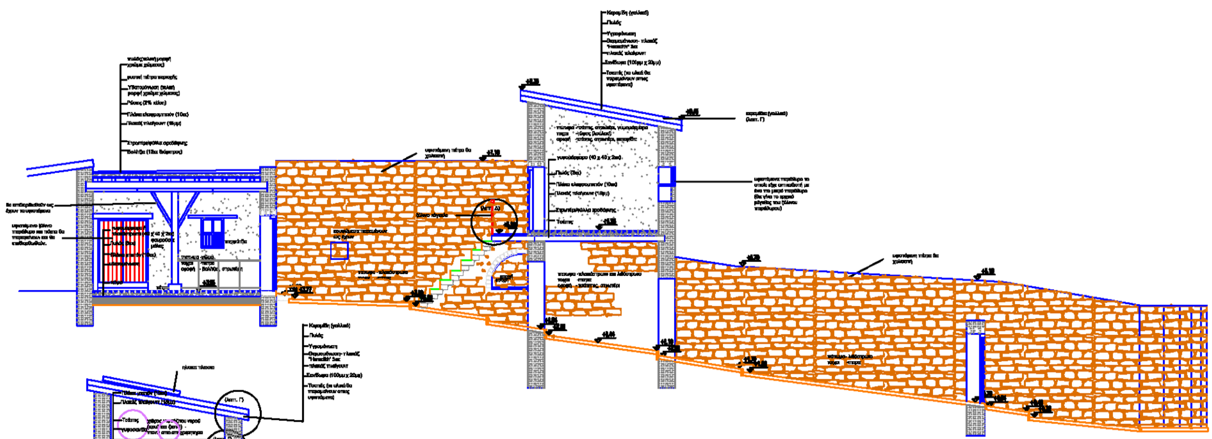
5. Building structure:

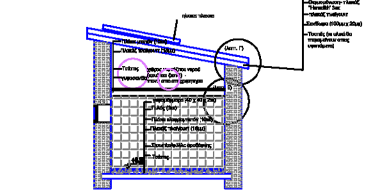
- Walls: 60cm stone wall
- Internal walls: 60cm stone wall and 10cm gypsum board, plaster, paint
- Roof: timber, wood, earth, 10cm thermal insulation, water barrier, ceramic roofing tiles
- Windows: wooden frame, double glazed, low emissivity, argon filled
- Floors: stone tiles

Main entrance, semi-open space, top floor



Floor plan(proposed)





South-north cross section through main entrance, top floor, living area (proposed)

6. Bioclimatic approach
    - Thermal mass: Floors, walls, staircase
    - Passive solar heating: Direct Gain (Glass openings and roof windows)
    - Solar Control:
        - External Shading Devices: External shutters
        - Floor overhangs
    - Natural Ventilation:
        - Night ventilation: In the summer nights all openings can be opened manually except the roof windows that are electrical.
        - Cross ventilation: Only the top bedroom had the potential to have openings on two sides.
        - Stack effect: In the 2 bedrooms and the kitchen, roof windows have been placed and are opened during the summer months. They also provide natural light since there are no openings in these spaces.
7. Auxiliary heating and cooling
    - Central heating-radiators (petroleum)
    - Fireplace (wood)
8. Open areas: Semi-open areas are created on the southern and northern side via overhangs, while the southern one is used as a yard. The open area is covered with tiling.
9. Occupant comments: The conditions inside the house during the summer months are ideal.

Original top floor

Top floor

Semi-open space, courtyard and top floor

Original bedroom

Original living room, kitchen, dinning area

Bedroom with roof opening

Living room, kitchen, dinning area

STUDENT DESIGN PROJECTS

Student design projects have been collected from various courses taught by the author at the Department of Architecture, University of Nicosia, Cyprus.

- Space and Light course
- Sustainable Design course
- Building Blocks for Social Sustainability workshops
- Bioclimatic Architecture course
- Energy Efficient Buildings course
- Sustainable Design Unit Studio

Through these courses, the climatic conditions Cyprus, thermal comfort, passive solar systems, vernacular and contemporary buildings, energy uses, building and energy legislations, building examples (academic and professional) were studied. A principal aim of the student work was to develop understanding of the criteria needed for an appropriate bioclimatic architecture that is sensitive to both energy use and climatic conditions.

The students were not only able to produce mature projects touching on all basic issues proclaimed by the course agenda, but most of them were able to greatly improve on their overall ability to solve complex architectural spaces and successfully present them in professional drawings and impressive computer renderings. This was partly the result of the instructors' perseverance and insistence that students should be handled as adults who are but a heartbeat away from professional employment.

Selected conference papers, student projects, research papers and teaching documents:

https://independent.academia.edu/SustainableDesignUnit

Selected design work, student life, photos, workshops and more info:

https://www.facebook.com/sustainable.design.unit

Space & Light Course

This is a fundamental course in natural lighting and its interaction with visual perception and aesthetics. The basic functions of natural lighting are studied, analysed and critiqued as design elements. Lecture topics include colour, light sources, measurement and control as they affect the interior environment. Students are asked to transfer this information to plans and specifications and are encouraged to explore how the luminous aspects of space can control subjective mood and convey symbolic values.

Instructor (2008-2018): Petros Lapithis

Assistant Instructors (2008-2017): Nikolas Tsaousis, Sophia Neokleous, Anna Margaritova, Kerry Kyriakou, Anthimos Papapericleous, Katerina Neofytidou

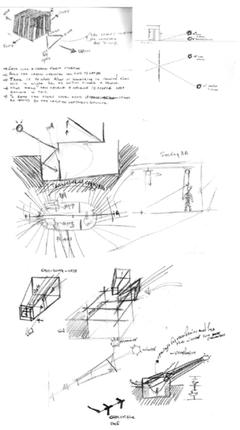
crypto-christians

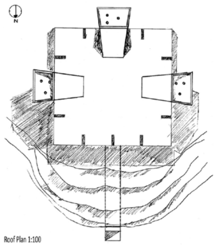
eastern orthodox church

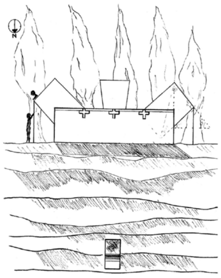
-The second largest single Christian communion in the world.
-It has between 226 and 300 million members worldwide.
-The term "Orthodox" translates from the Greek to mean "Corectly Beilieving" or "Correctly Glorifying God" (from the adjective orrthos= correct, right and the verb dokeo,-o= I see, I believe or the noun doxa = glory)\
-It is consider by its adherents to be the One, Holy, Catholic and Apostolic Church established by Christ and his Apostles nearly 2000 years ago.
-Vespers - (Greek Esperinos) Sundown, the begining of the liturgical day
-Matins (Greek Orthos) - First service of the morning. Uaually starts before sunrise.

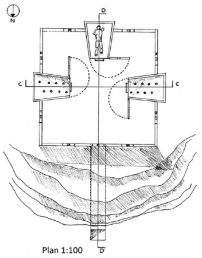
the concept

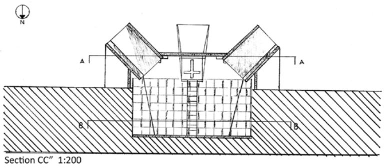
-The Cross.
-The crypto-Christians.
-The site is situated in Turkey.
-The restrictions to-day in Turkey about their believes the face extinction.
-The crypto-Cristians life is very difficult because they practice both of the rituals; the one they strongly believe and the other that they force to believe.
-The worship space is situated in farm storage for hey.
-There is no altar or chairs or icons something to remind that this is a church.
-The signs is the cuts on the walls and the roof.

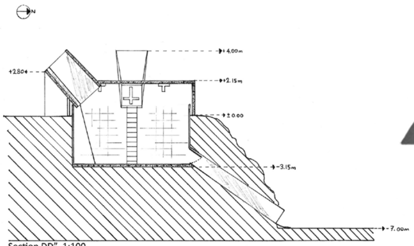


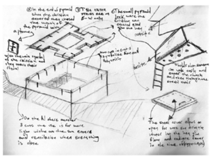


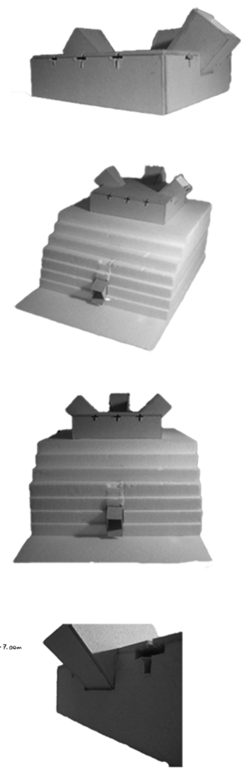


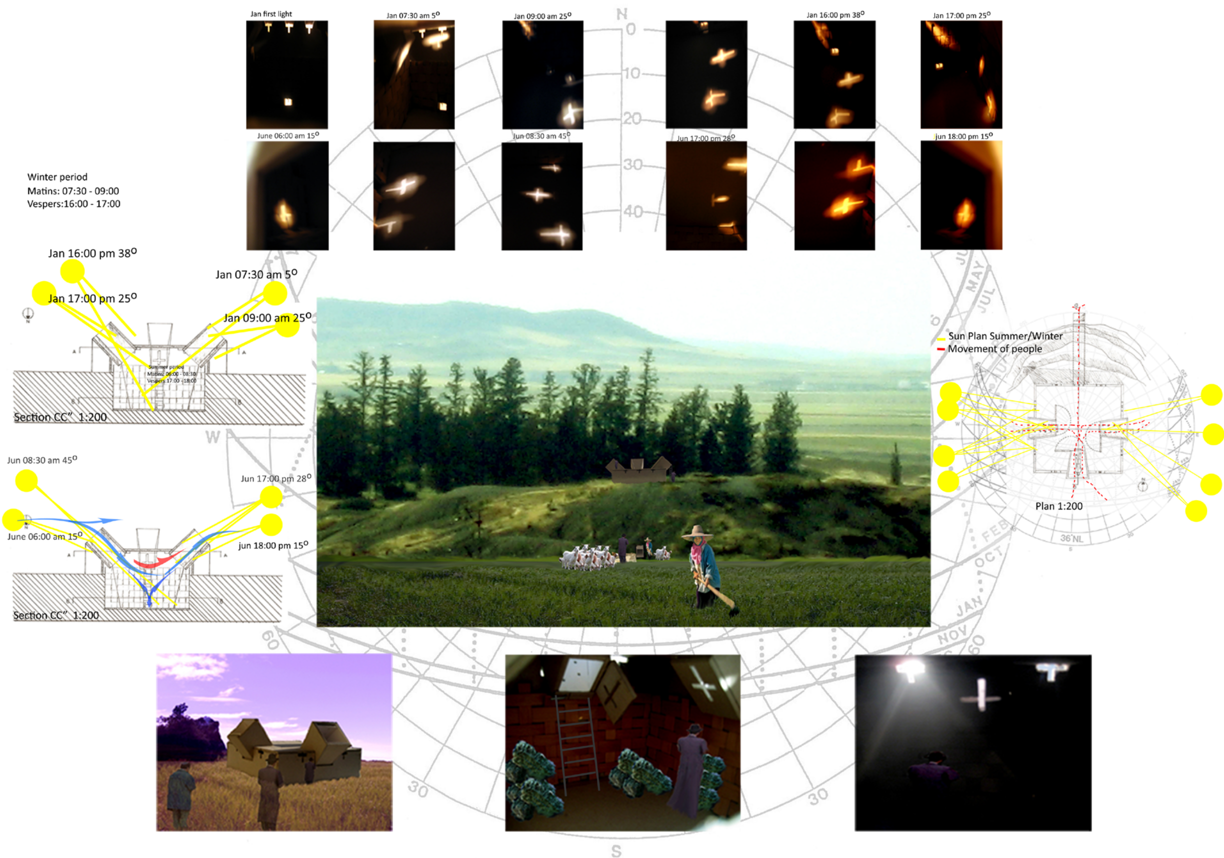




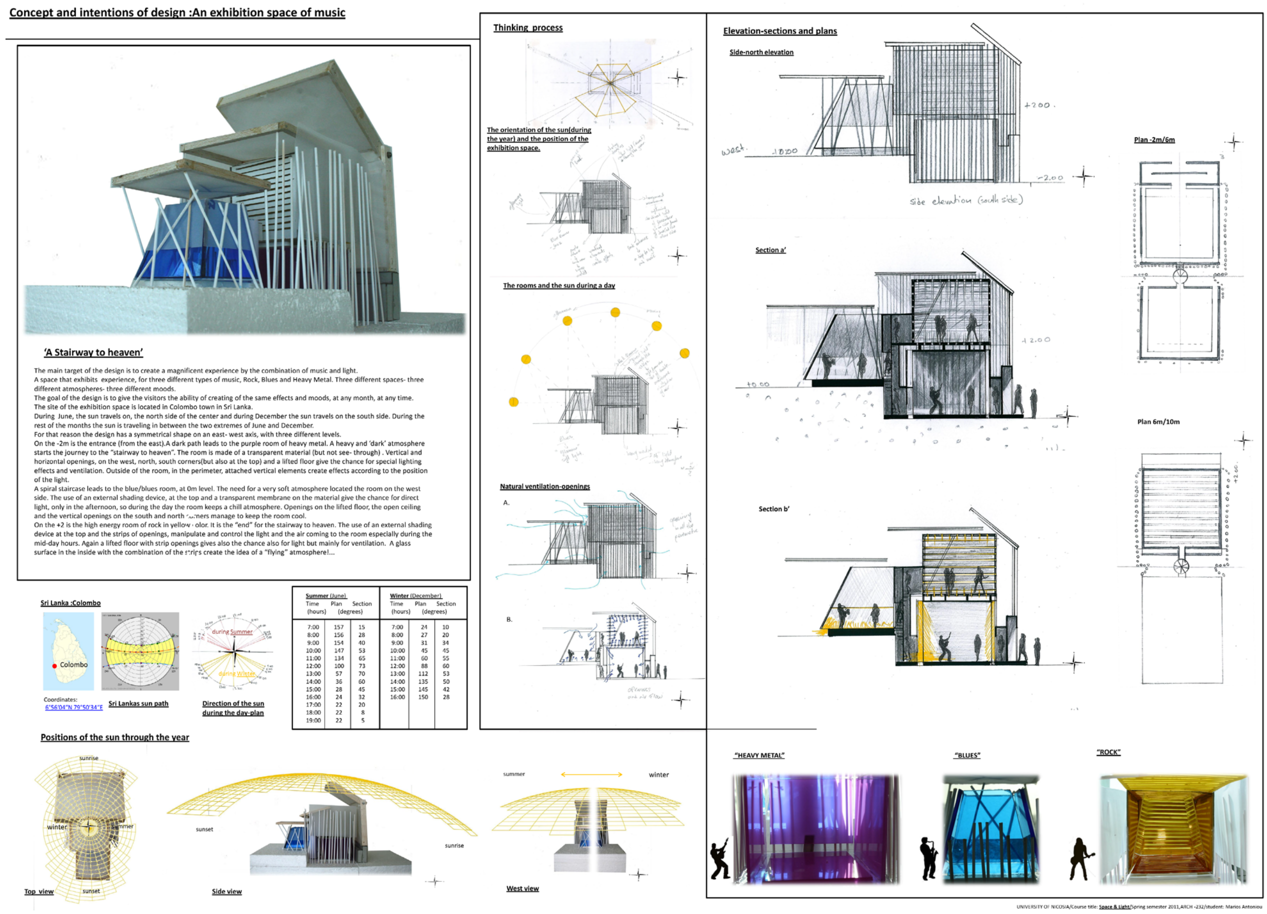






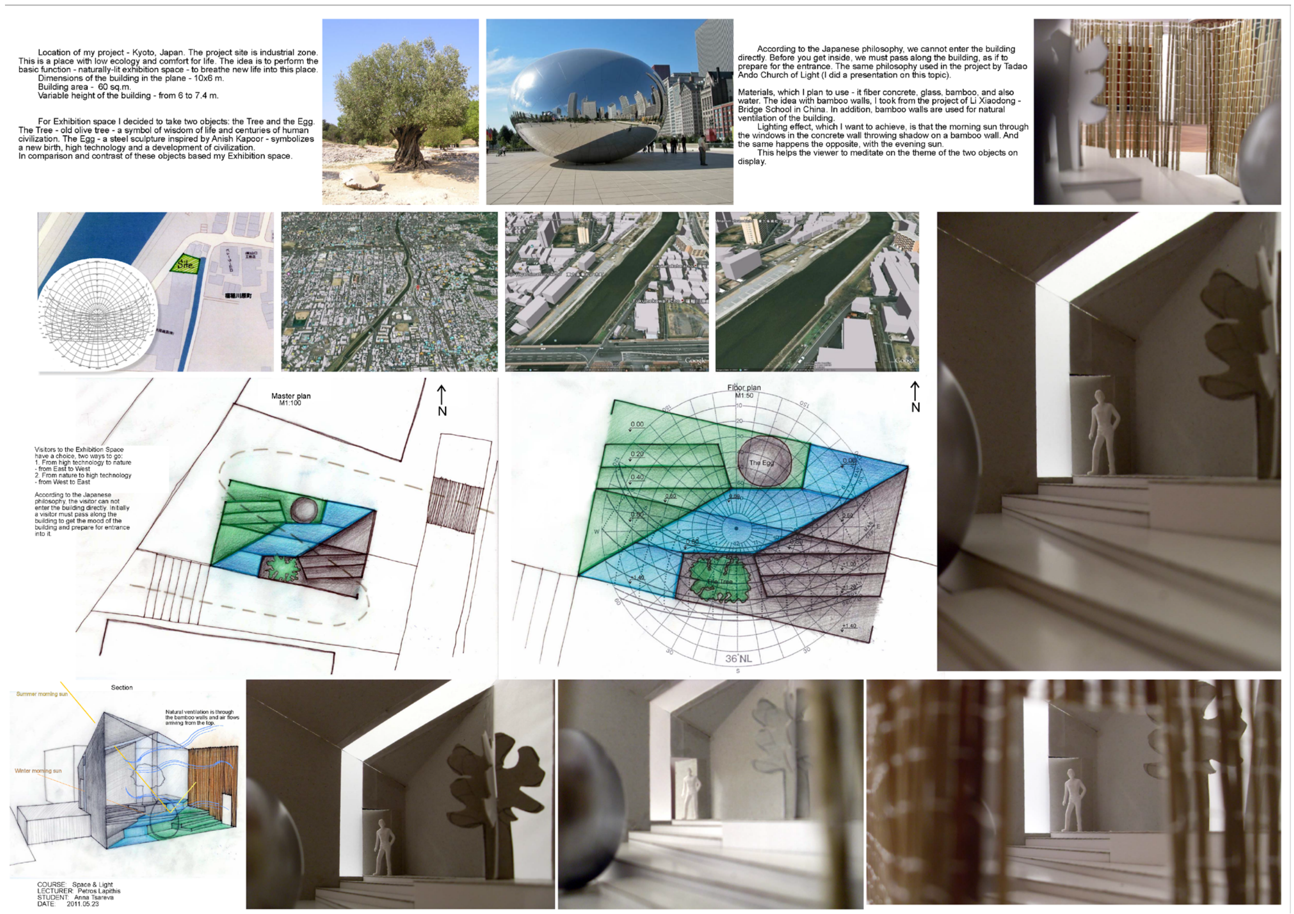


Crypto-Christians worship space. Nikolas Tsaoushis. 2009

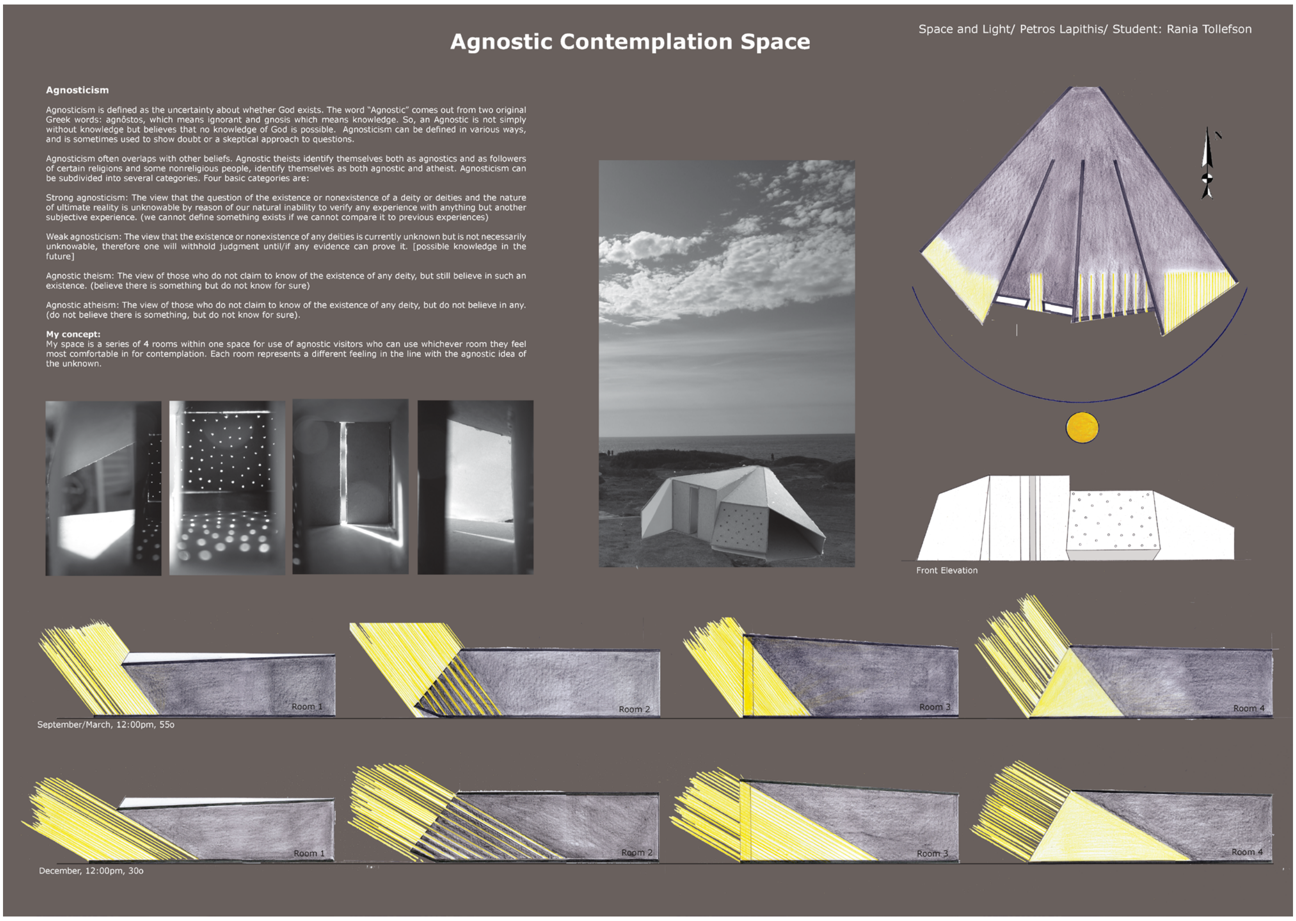


Summer (June) Time (hours)	Plan (degrees)	Section	Winter (December) Time (hours)	Plan (degrees)	Section
7:00	157	15	7:00	24	10
8:00	156	28	8:00	27	20
9:00	154	40	9:00	31	34
10:00	147	53	10:00	45	45
11:00	134	65	11:00	60	55
12:00	100	73	12:00	88	60
13:00	57	70	13:00	112	53
14:00	36	60	14:00	135	50
15:00	28	45	15:00	145	42
16:00	24	32	16:00	150	28
17:00	22	20			
18:00	22	8			
19:00	22	5			

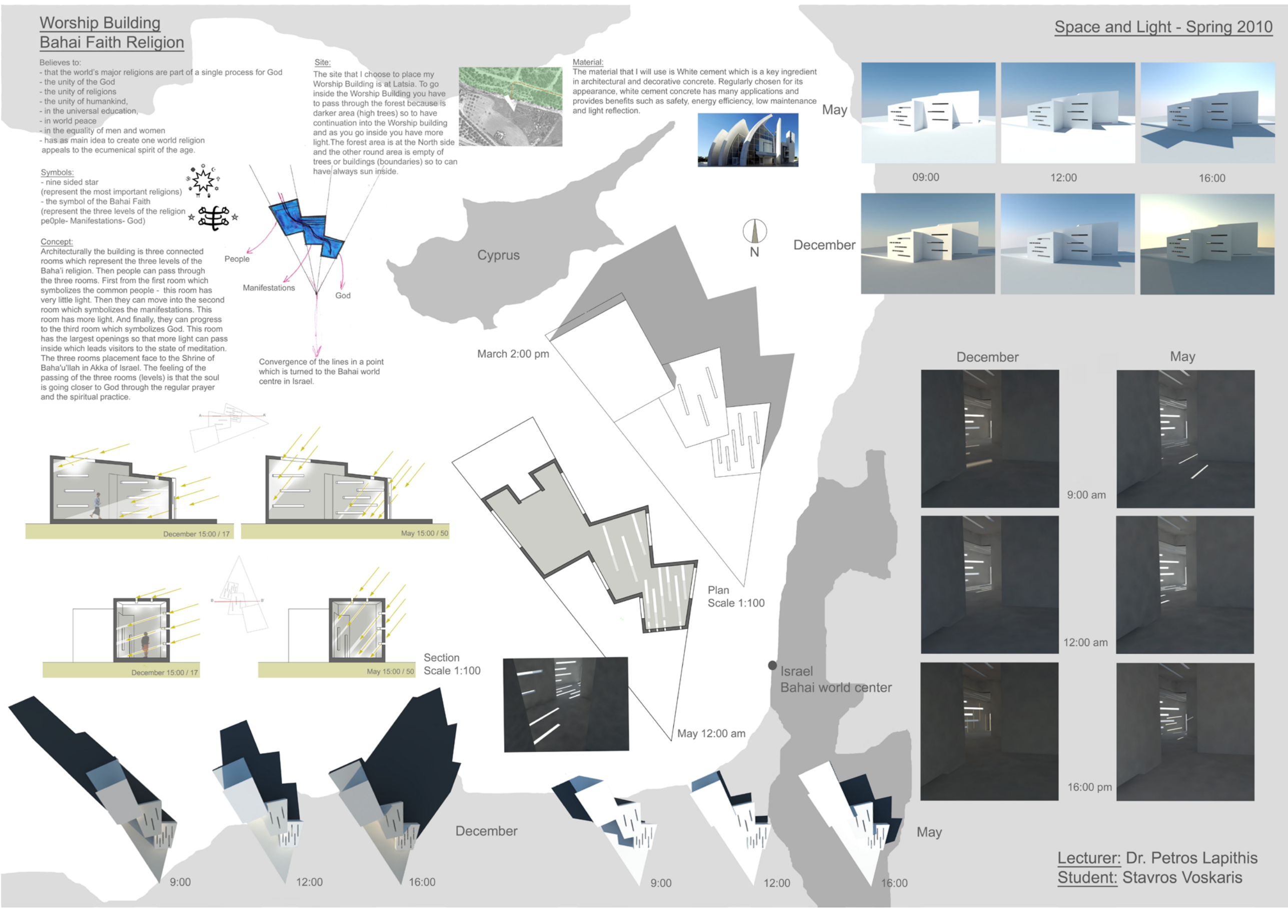
Music Exhibition Space. Marios Antoniou. 2011



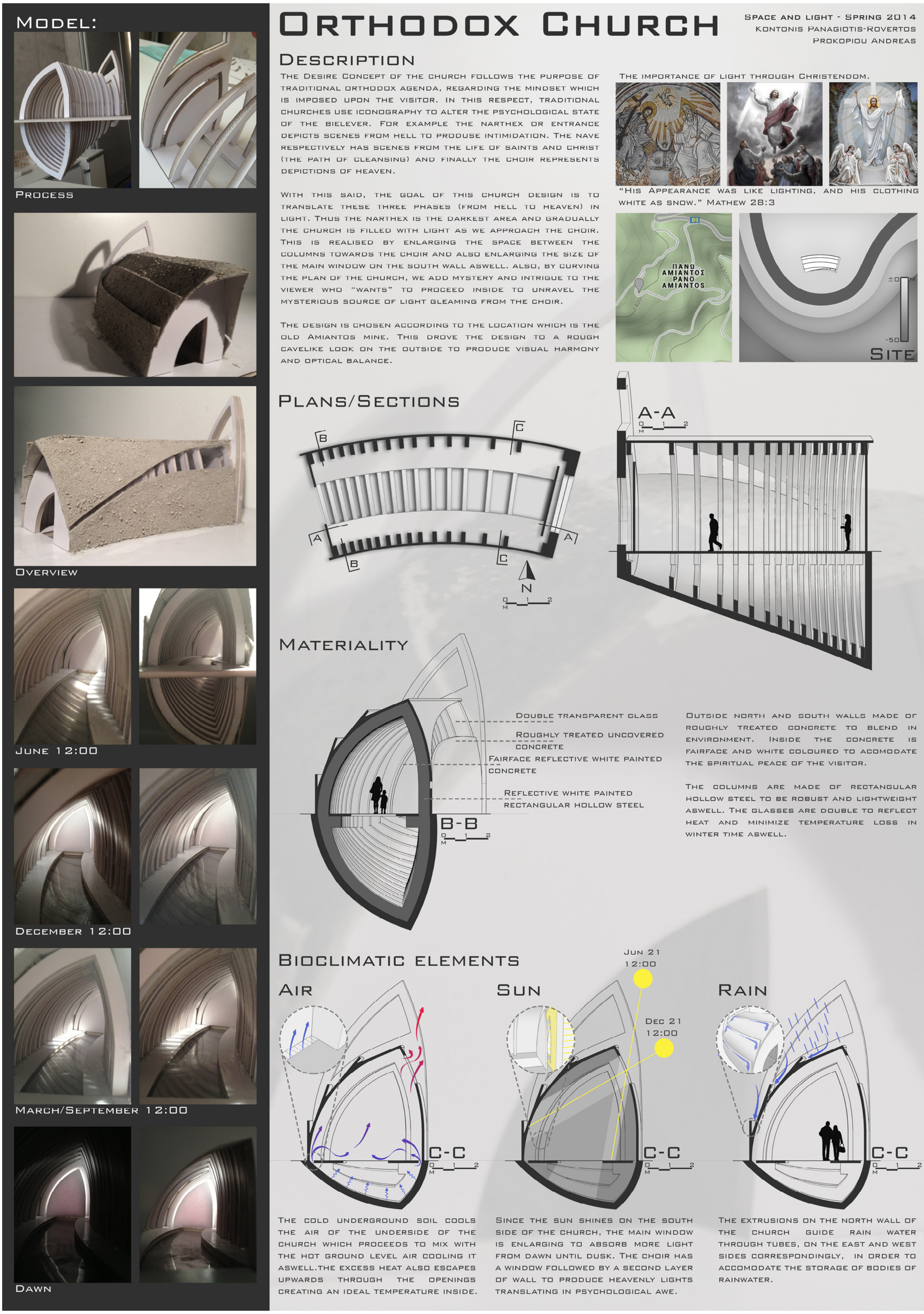
Tree and the Egg Exhibition Space. Anna Tsareva. 2011



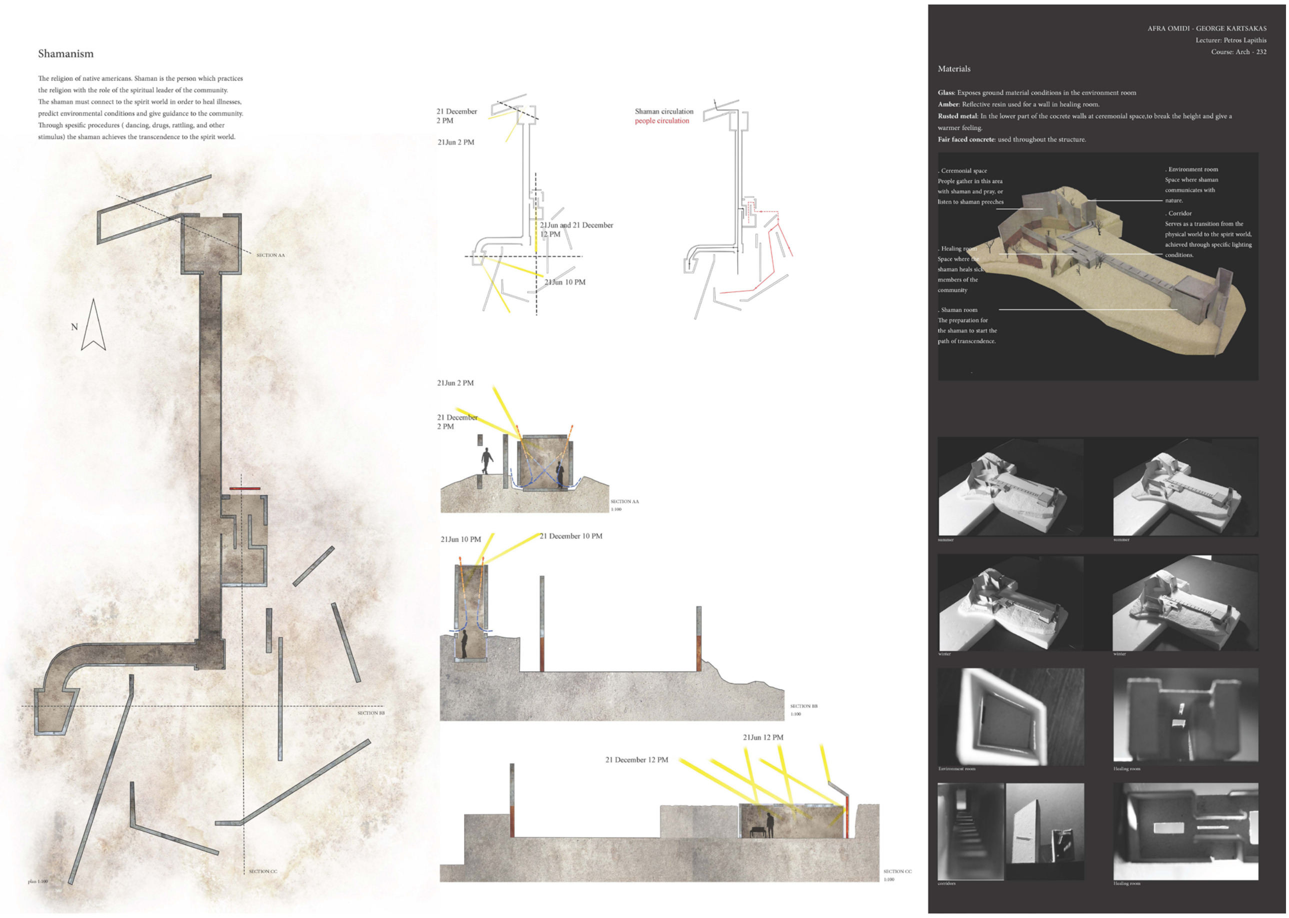
Agnostic Contemplation Space. Rania Tollefson. 2010



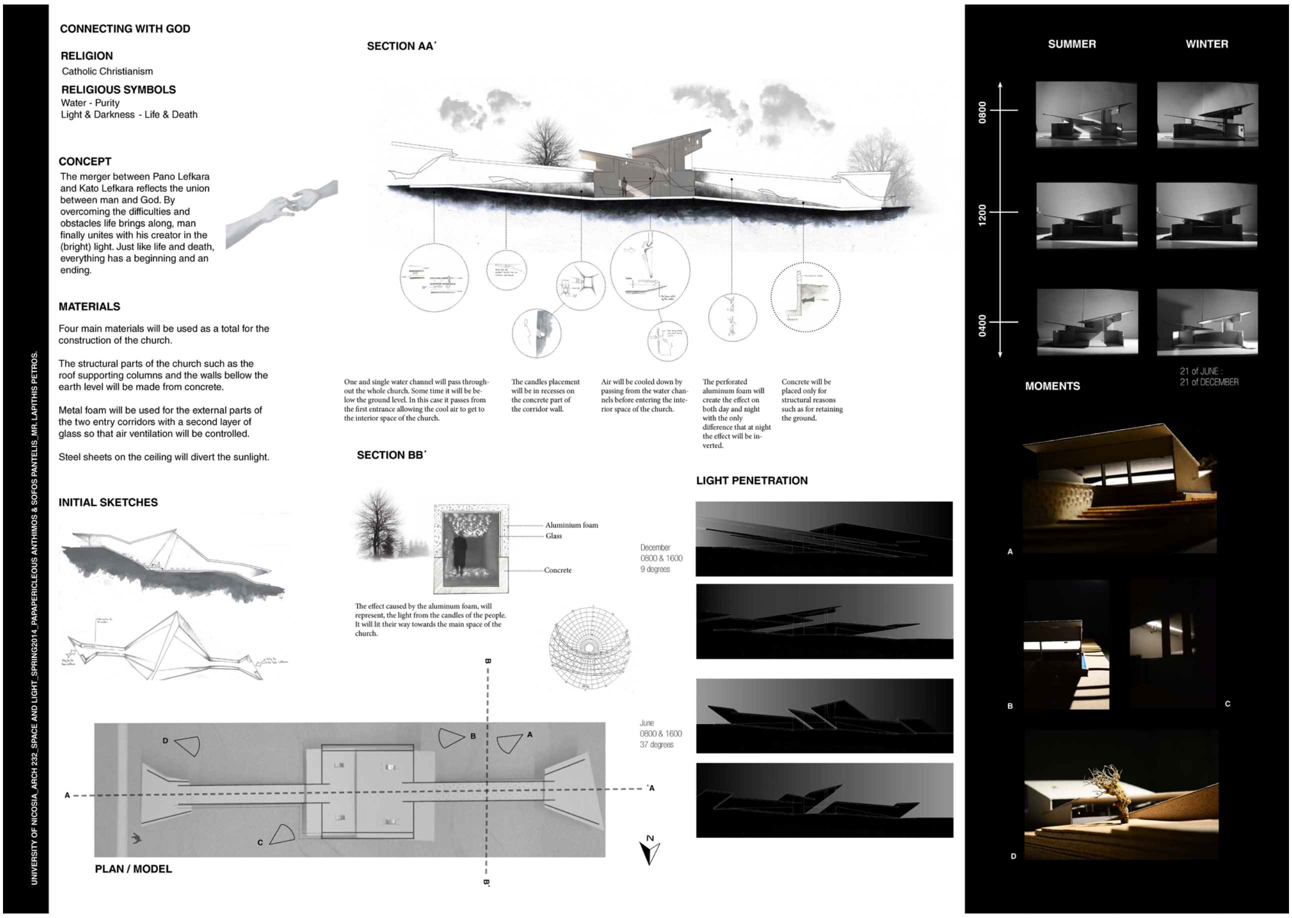
Bahai Worship space. Stavros Voskaris. 2010



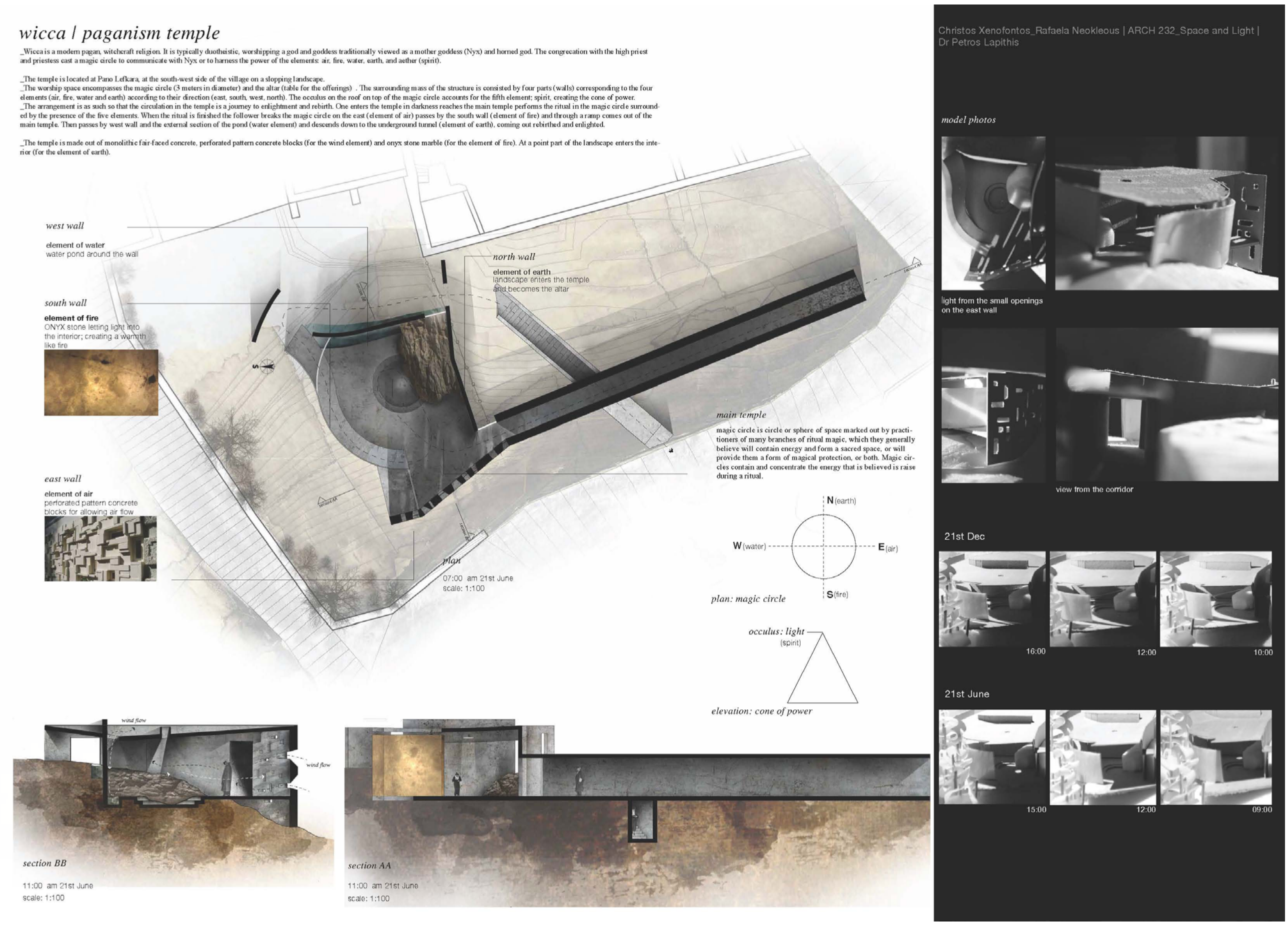
Orthodox Church. Andreas Prokopiou, Panayiotis Kontonis. 2014



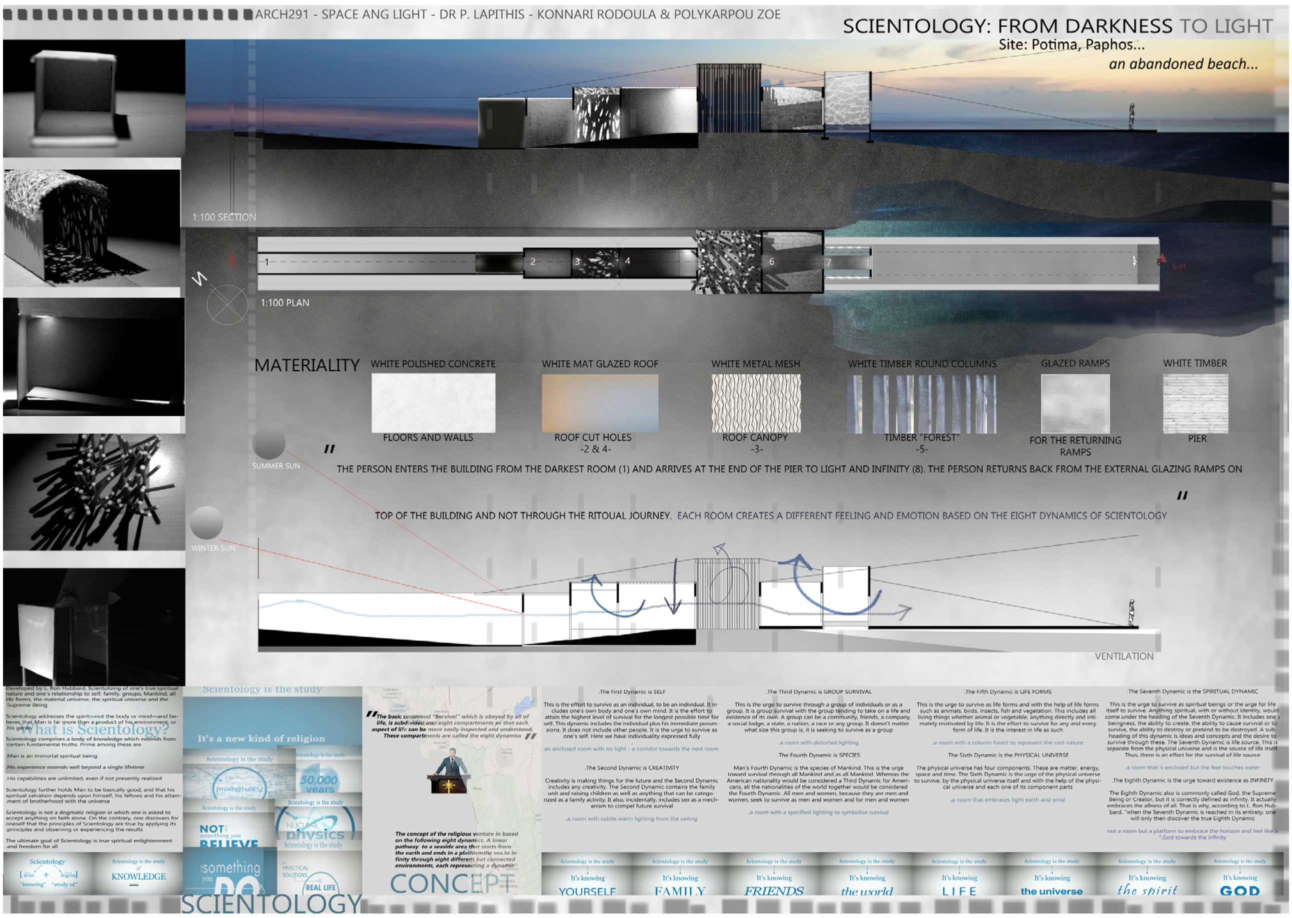
Shamanism. Afra Omidi, George Kartsakas. 2014



Catholic Christianism. Anthimos Papapericleous, Pantelis Sofos. 2014



Wicca. Christos Xenofontos, Rafaela Neokleous. 2014



Scientology. Rodoula Konnari, Zoe Polykarpou. 2014

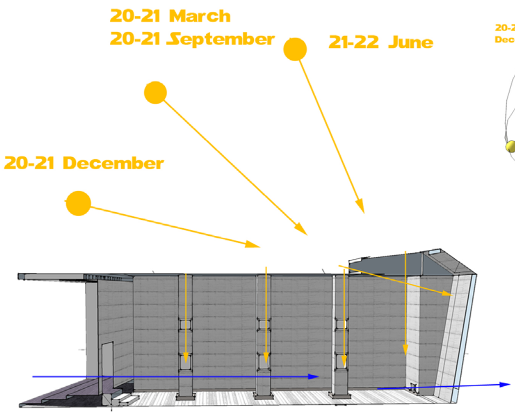
THE TEMPLE OF THE FORCE

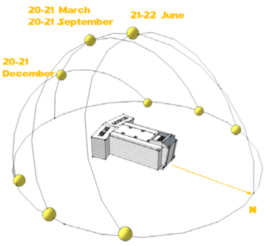
There is no emotion, there is peace.

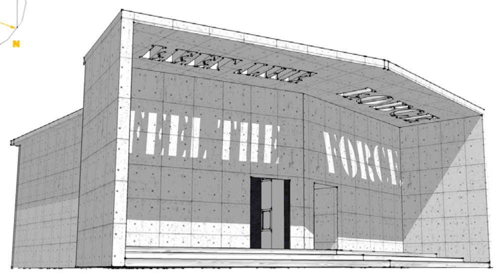
There is no ignorance, there is knowledge

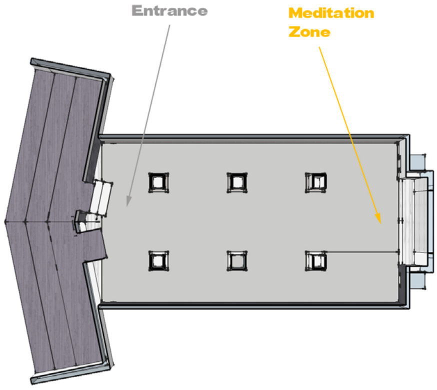
There is no passion, there is serenity

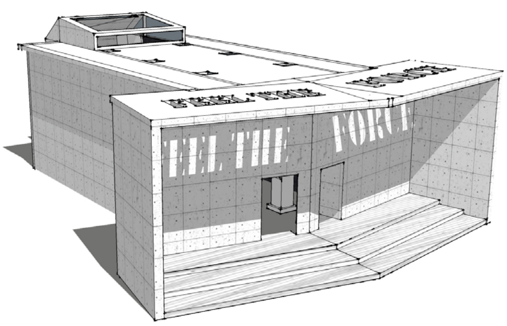
There is no death, there is the **Force**











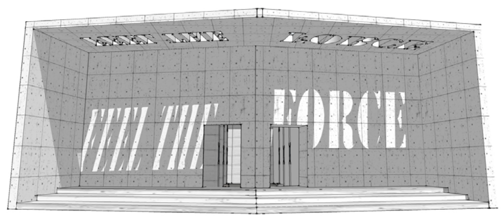
The temple is located on a hill in the village of Oroklini, near Larnaca

The light falls on the facade through a hole in the visor, forming the words "Feel the Force."

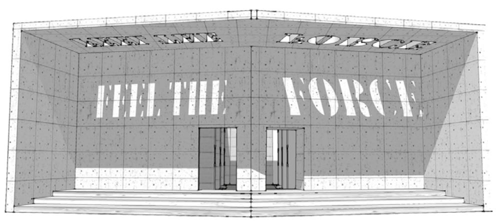
The temple is divided into two parts. First part - Entrance represents the world of men. Second one is a place for meditation. Entrance is a grim part of the temple. Area for meditation is strongly illuminated by a window, located at the top. If in this part of the church you raise your head, you can see the sky.

These two parts are connected together by two rows of columns. They are blank inside. The light passes through them and points the way through the darkness to enlightenment.

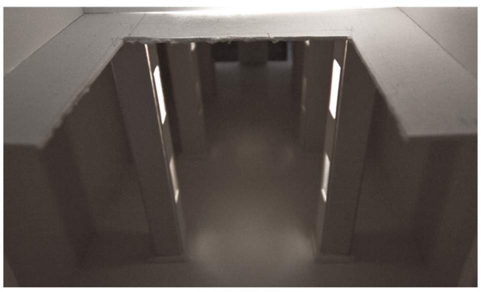
June 12 am



September 12 am

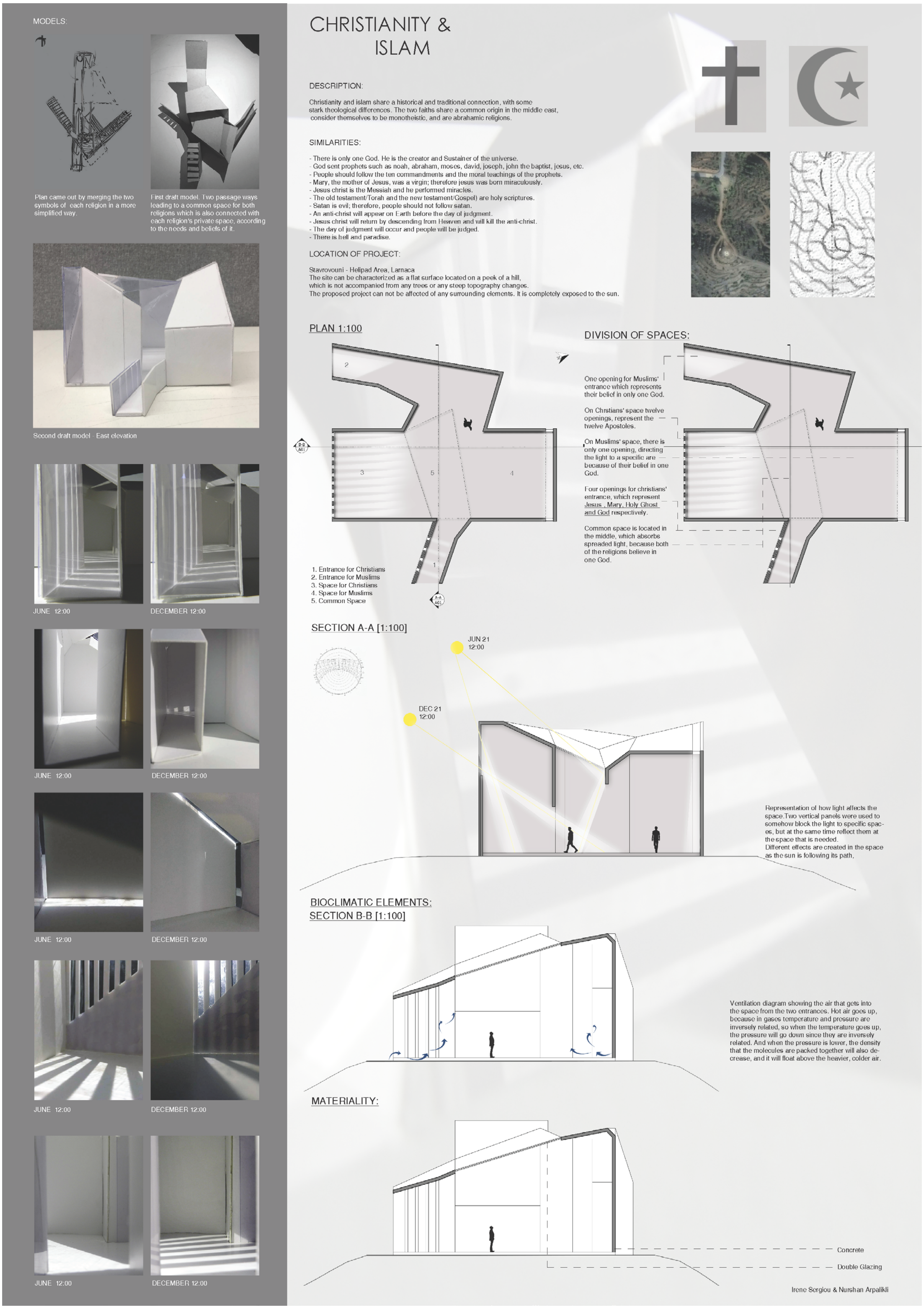


The temple is made of modern and minimalist materials . The facade is sheathed concrete tiles, internal walls are plastered. The floor is made of light wood. In the temple there are no superfluous elements of the interior that would not distract people from understanding the force.

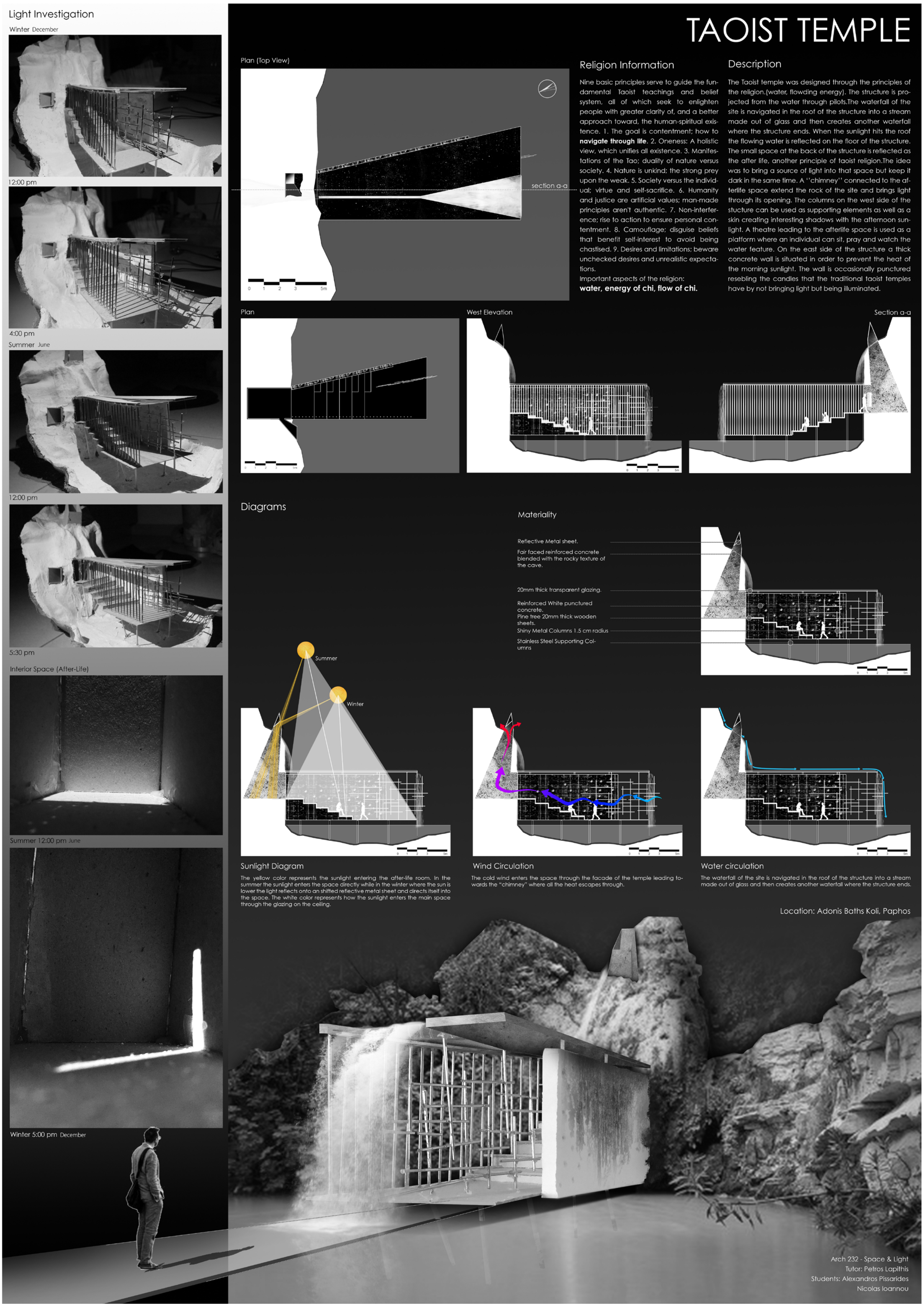


MOSOLOV EGOR

Temple of the Force. Egor Mosolov. 2012



Christianity and Islam. Irene Sergiou, Nurshan Arpalikli. 2016

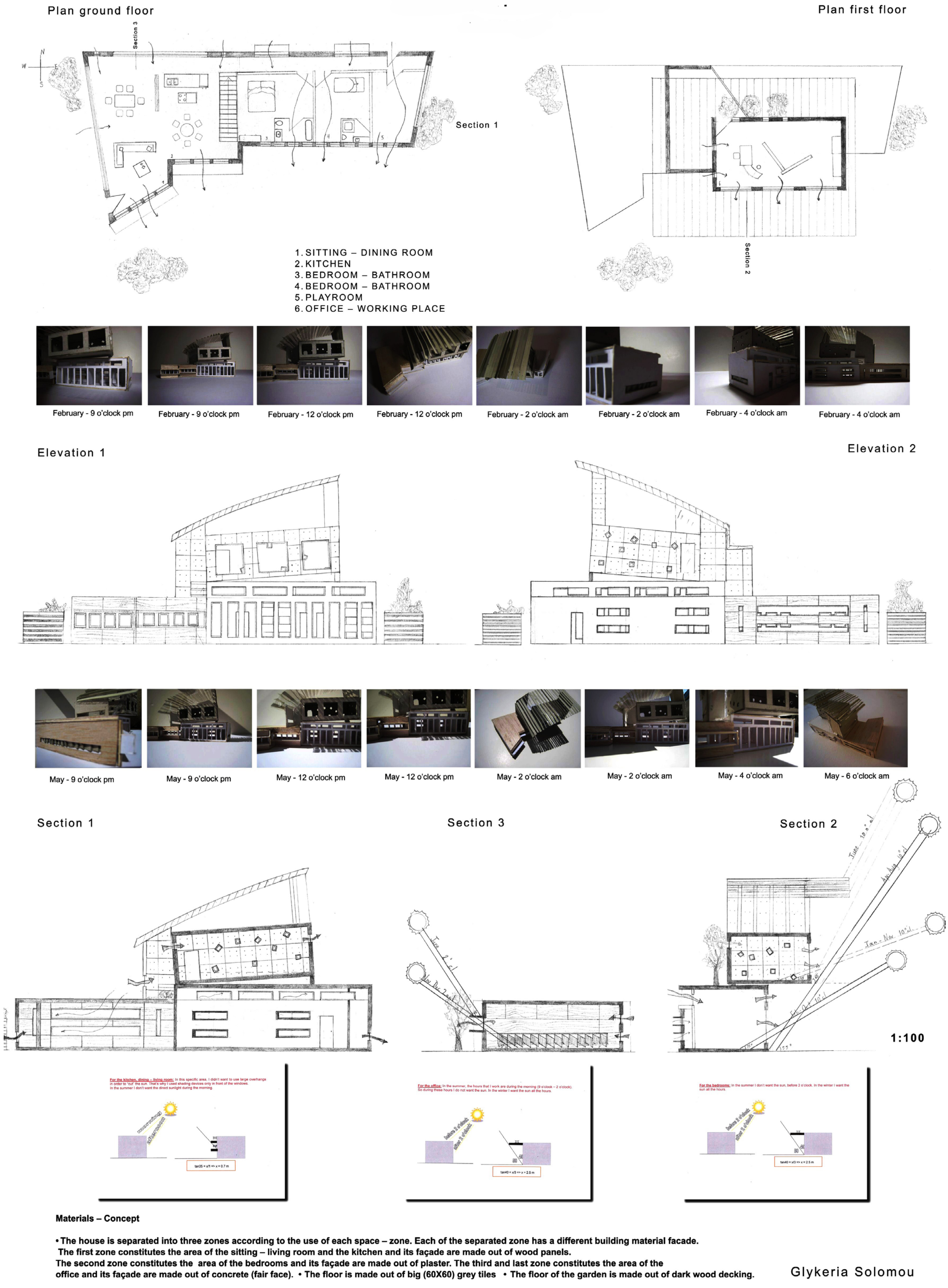


Taoist temple. Nicolas Ioannou, Alexandros Pissarides. 2016

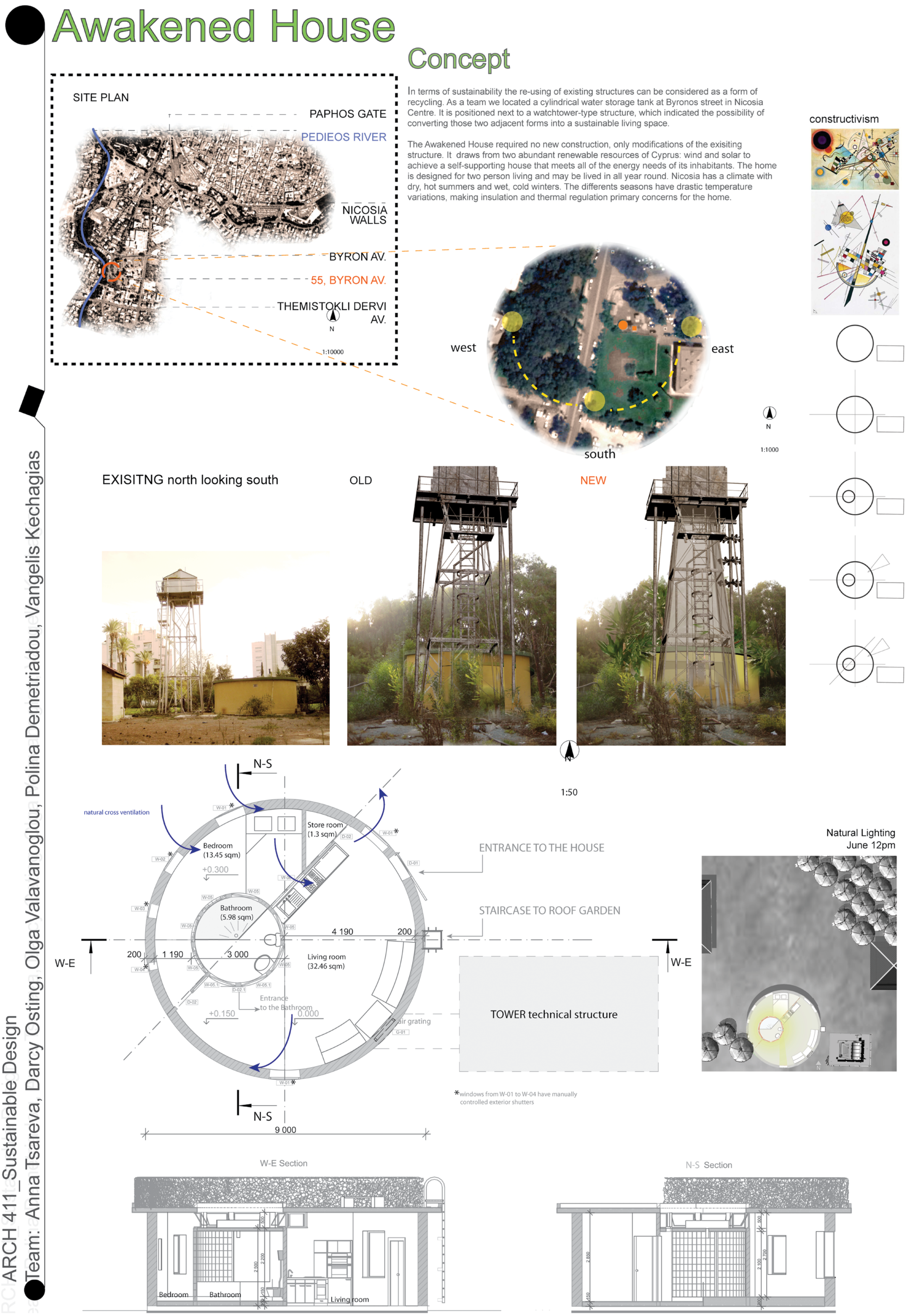
Sustainable Design Course

The course studies the human and social impact of the built environment upon the inhabitants of that environment: physically, emotionally and psychologically. Contemporary perspectives on the relationship between human behaviour, designed environments and energy efficiency are examined. The course explores the implications on those relationships for the purpose, nature and future direction of design education, design research and design practice. Students become aware of design factors affecting indoor comfort and explore concepts, structures and techniques that lie behind the realisation of energy conscious design.

Instructor (2009-2015): Petros Lapithis



Ecohouse. Glykeria Solomou. 2008

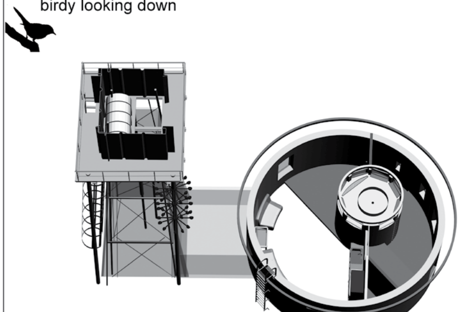


Awakened House: Anna Tsareva, Darcy Osting, Olga Valavanoglou, Polina Demetriadou, Vangelis Kechagias. 2011

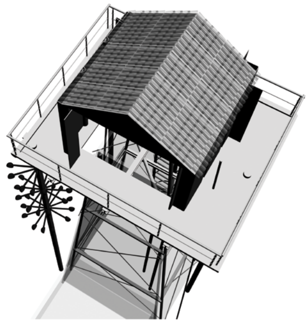
ARCH 411_Sustainable Design
Team: Anna Tsareva, Darcy Osting, Olga Valavanoglou, Polina Demetriadou, Vangelis Kechagias

The Awakened House relies entirely on qualities of the exisiting structure such as height of the tower for wind collection and water storage for heating, while taking advantage of the site propeties such as wind direction, direct sunlight, and privacy to design a comfortable and self-sufficient energy system to meet the needs of the occupants.

birdy looking down



north looking south

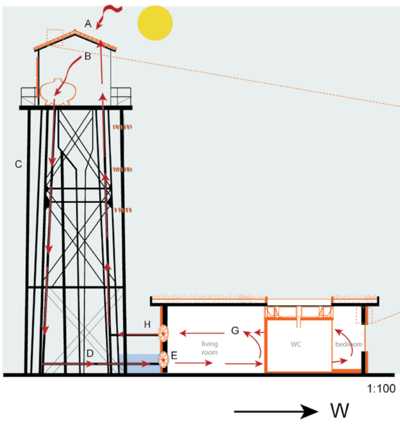


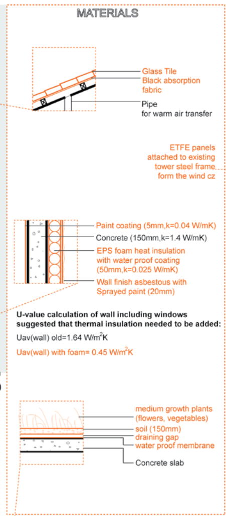
western view

psipsis looking up

PASSIVE SYSTEMS (old + new)

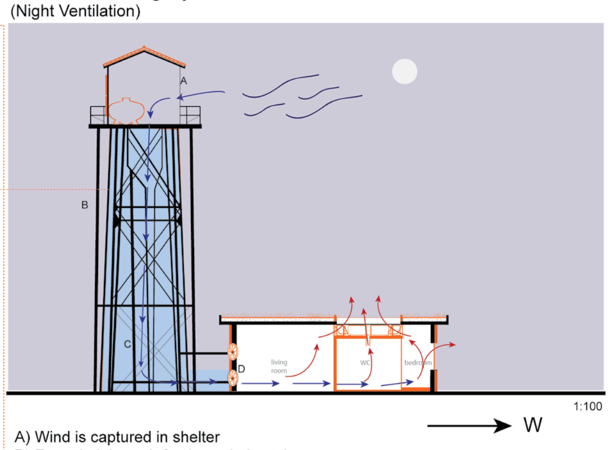
Winter Convective Heating





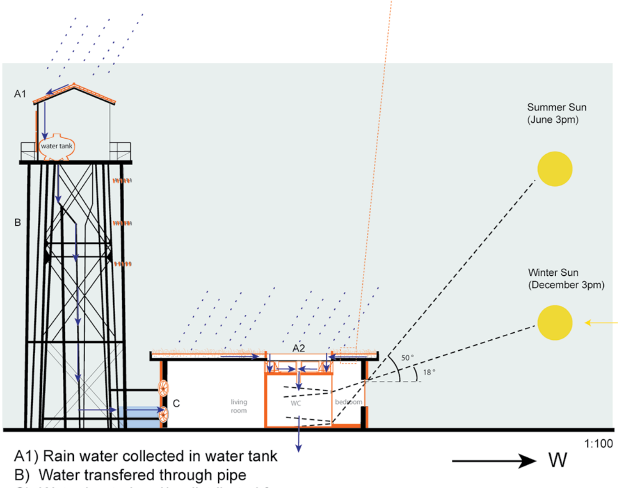
A) Sunlight enters through glass tiles
B) Black absorbant layer traps warm air
C) Warm air is pulled into pipe
D) Air is pulled down by fan
E) Enters house at floor level (living room and then bedroom)
F) Convective loop is created
G) Air circulates throughout space to ceiling
H) Reclaimed through pipe to be reheated

Summer Cooling System
(Night Ventilation)



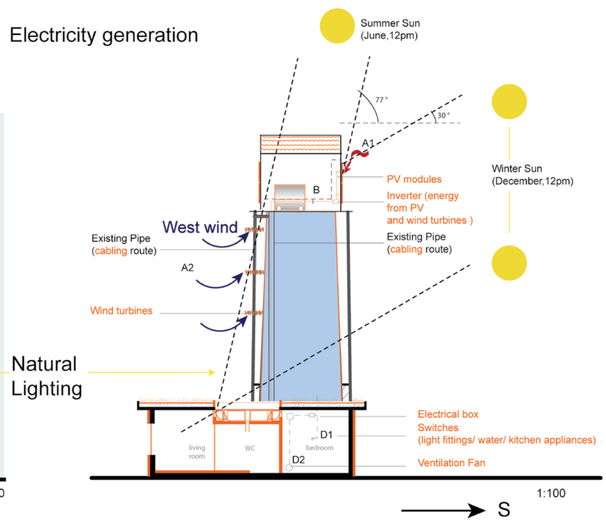
A) Wind is captured in shelter
B) Funneled through fan into wind catcher
C) Cool air sent through tunnel connected with house
D) Exhausted into building through fan at output

Rain water harvesting

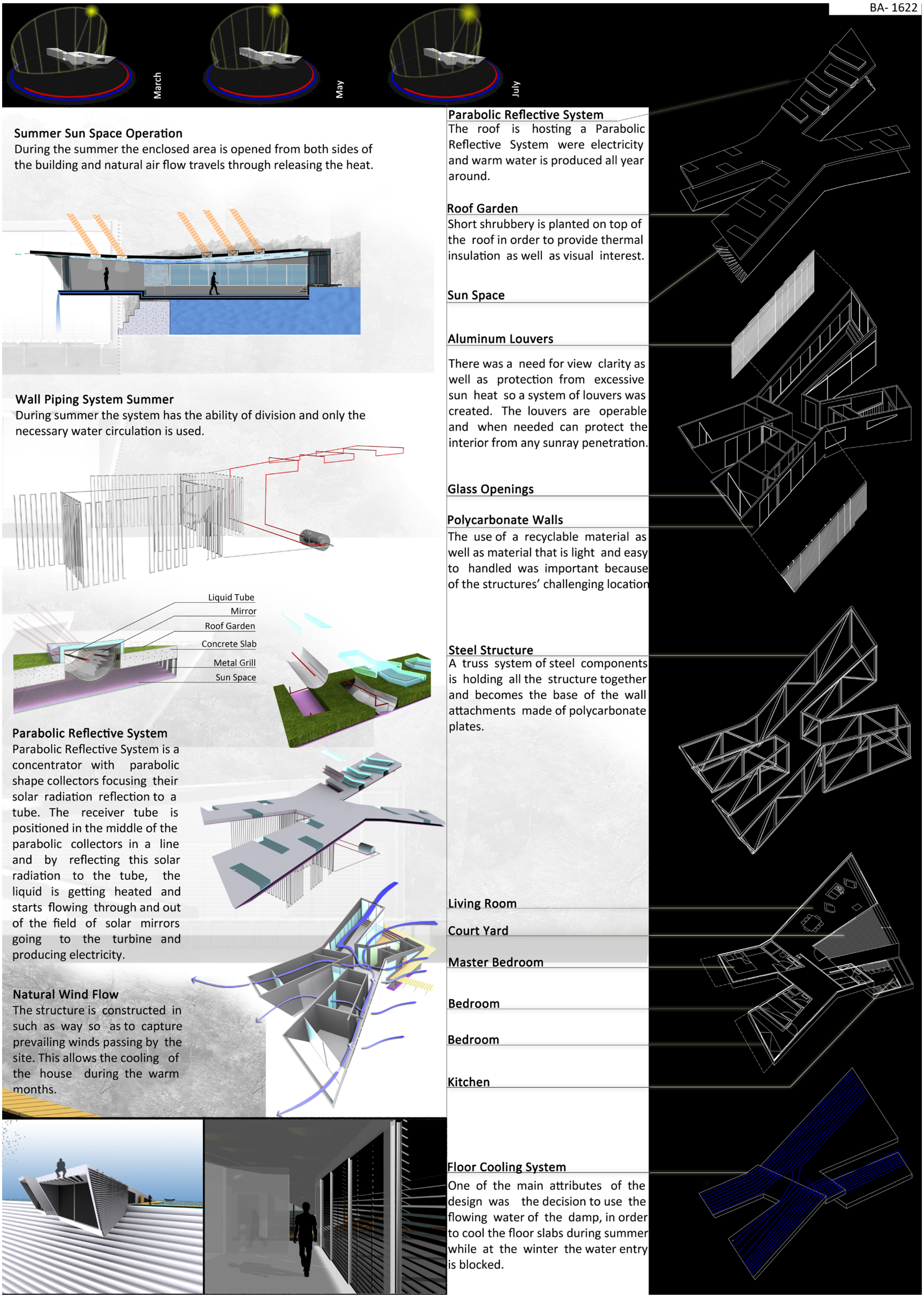


A1) Rain water collected in water tank
B) Water transfered through pipe
C) Water heated and/or distributed for usag
A2) Rain water excess from roof drained
through shower (*rain in the house*)

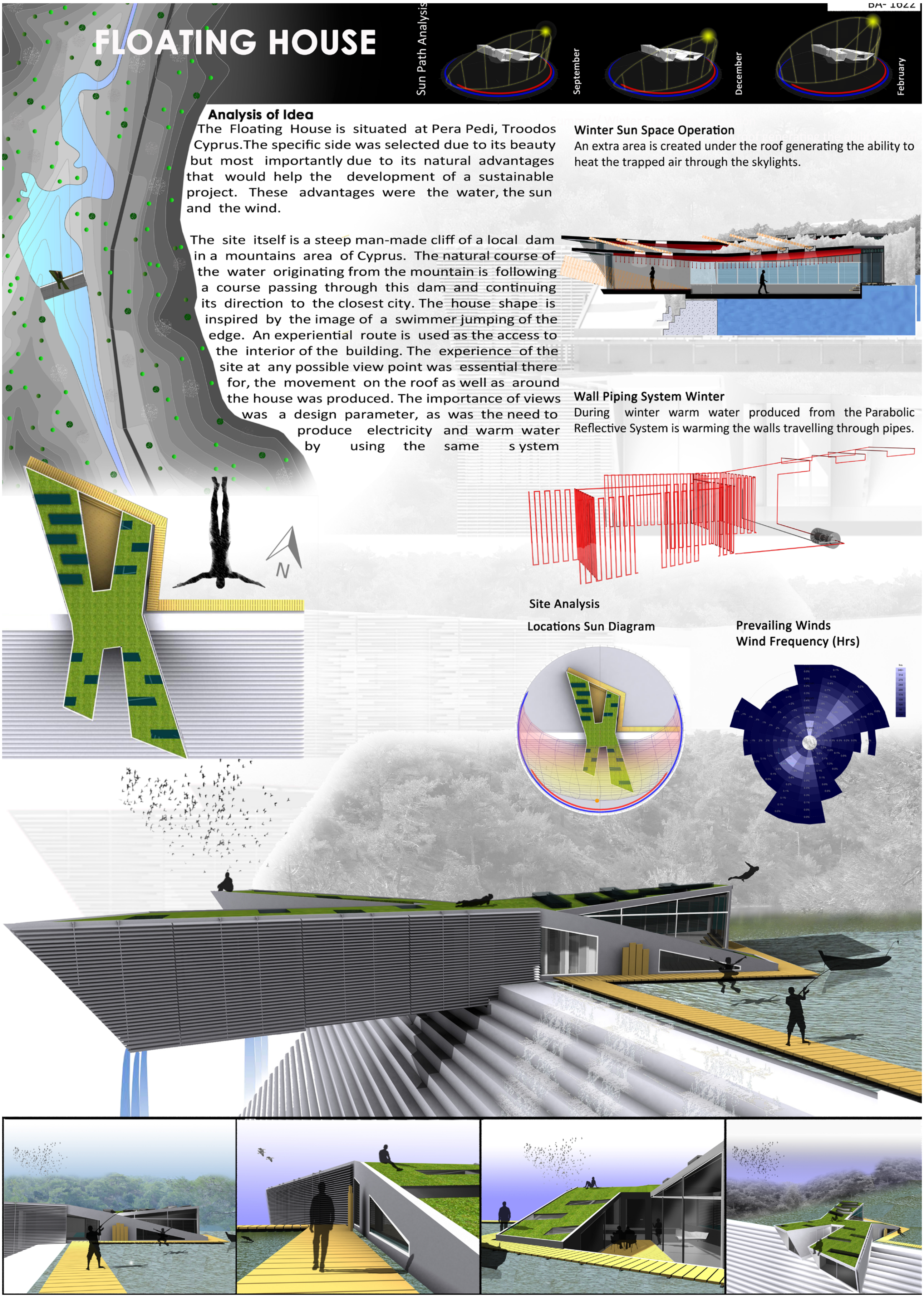
Electricity generation



Awakened House: Anna Tsareva, Darcy Osting, Olga Valavanoglou, Polina Demetriadou, Vangelis Kechagias. 2011



The Floating House: Sophia Neocleous, Alexandros Postekkis, Vrahimis Moutiris. 2009



The Floating House: Sophia Neocleous, Alexandros Postekkis, Vrahimis Moutiris. 2009

Xyliatos Dam

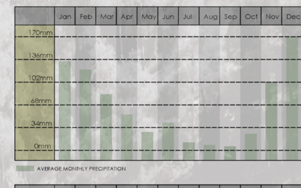
BA-1364

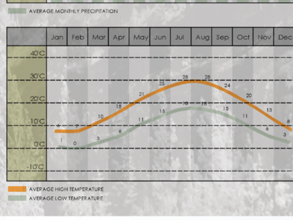
Concept, the purposed idea refers to the development of a sustainable house of 120m2 for 4 persons. In the existing location there are 3 rivers ending in the dam and the idea was to make a fourth river so the house becomes part of the environment. That's also the reason that the one part of it is inside the earth and the other half is cantilevered above the water. To go inside the house you have an experience of a circulation above the ground and then underneath the earth and finally a surprise of an open view.

Bioclimatic concept, To achieve a building that is more sustainable, the whole life of the construction process. The environmental impacts: **use**, **heating**, **lighting** and **cooling** have to be considered. Also the use of proper materials and intelligent natural cooling and heating systems was found necessary.

Materials

Concrete used for the main construction, reduces CO2 emissions over its Life Cycle. Through passive cooling and heating techniques concrete reduces the energy demand in less than 8Kwh/m2 for cooling and heating.
Double-glazing reduces thermal and acoustic properties, heating costs, save energy and help to reduce global warming. Metal or metallic oxide layers deposited on a sealed unit's internal surface. They reduce the U-Value by suppressing radioactive heat flow.
Heat double - glazed windows used at the sides of the house, keep the collected heat from the sun inside, while in summer the sun is reflected away to keep the interior cool.
Laminated glass used for the ramps: two or more sheets of glass are placed together with one or more layers of PVB (polyvinyl butyral, a type of plastic) between them. Laminated glass is a type of safety glass.





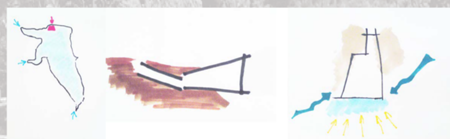
Shading devices

External shading devices effectively minimize solar heat gain in the summer period, by 30% compared to internal ones.
Bright metallic color used for the louvers gives about 20% more protection than dark ones. White or light color solar shading is the best reflector of solar radiation. Inside the building it re-radiates heat into the room and also warms the air by convection.
Internal and **external** shading devices used in the house can be adjustable devices or set to intercept the direct rays of the sun and reflect some of it onto the ceiling and walls reinforcing the daylight at the back of the room.
The louvers in the sides are fixed to insure the optimum protection from the angels of the sun.

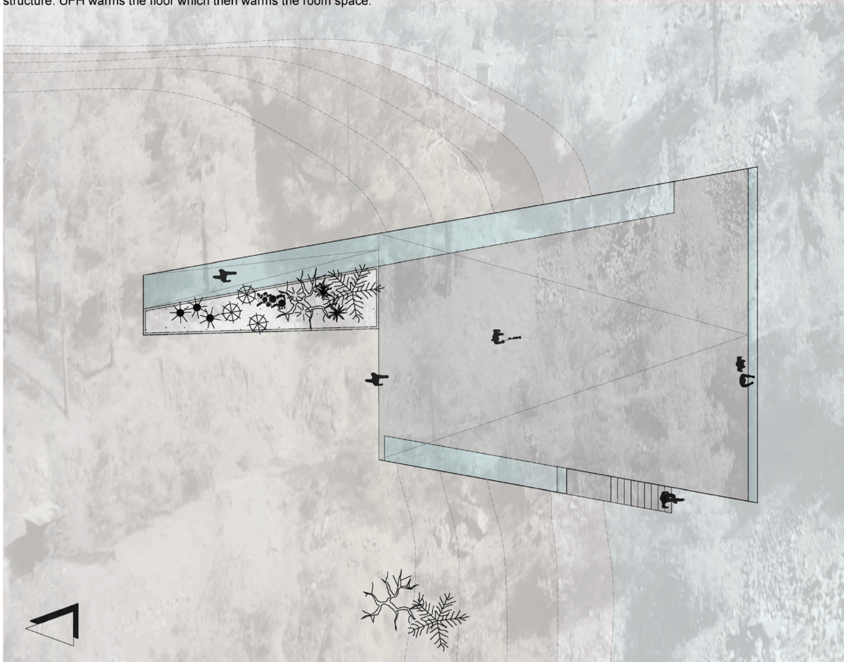
Using Renewable energies

Photovoltaic
Light weight flexible photovoltaic was used on the louvers located horizontally to provide electricity for the house.
Heating collectors
Underneath the laminated glass pipes were placed to collect heat from the sun.
Geothermal cooling and heating systems
Heat pumps were located inside the earth and deep in the dam to transfer heat from one position to another. In summer heat pumps transfer heat from the house down into the ground, thus cooling the environment much like a refrigerator. Also Geothermal heating works by absorbing heat from the earth, which maintains a nearly constant temperature of between 10C to 16C (50F to 60F) in the house.
Under floor heating System designed to operate with a heat pump.
Three variables are used in the design, to determine output: • water temperature • water flow • pipe spacing. The material of the under floor heating pipes is UFH. The basic principle of UFH is that heated water is circulated through pipes, these are usually plastic or a plastic and metal composite, that are buried in the floor structure. UFH warms the floor which then warms the room space.

Site Plan 1:10000



fourth river location orientation



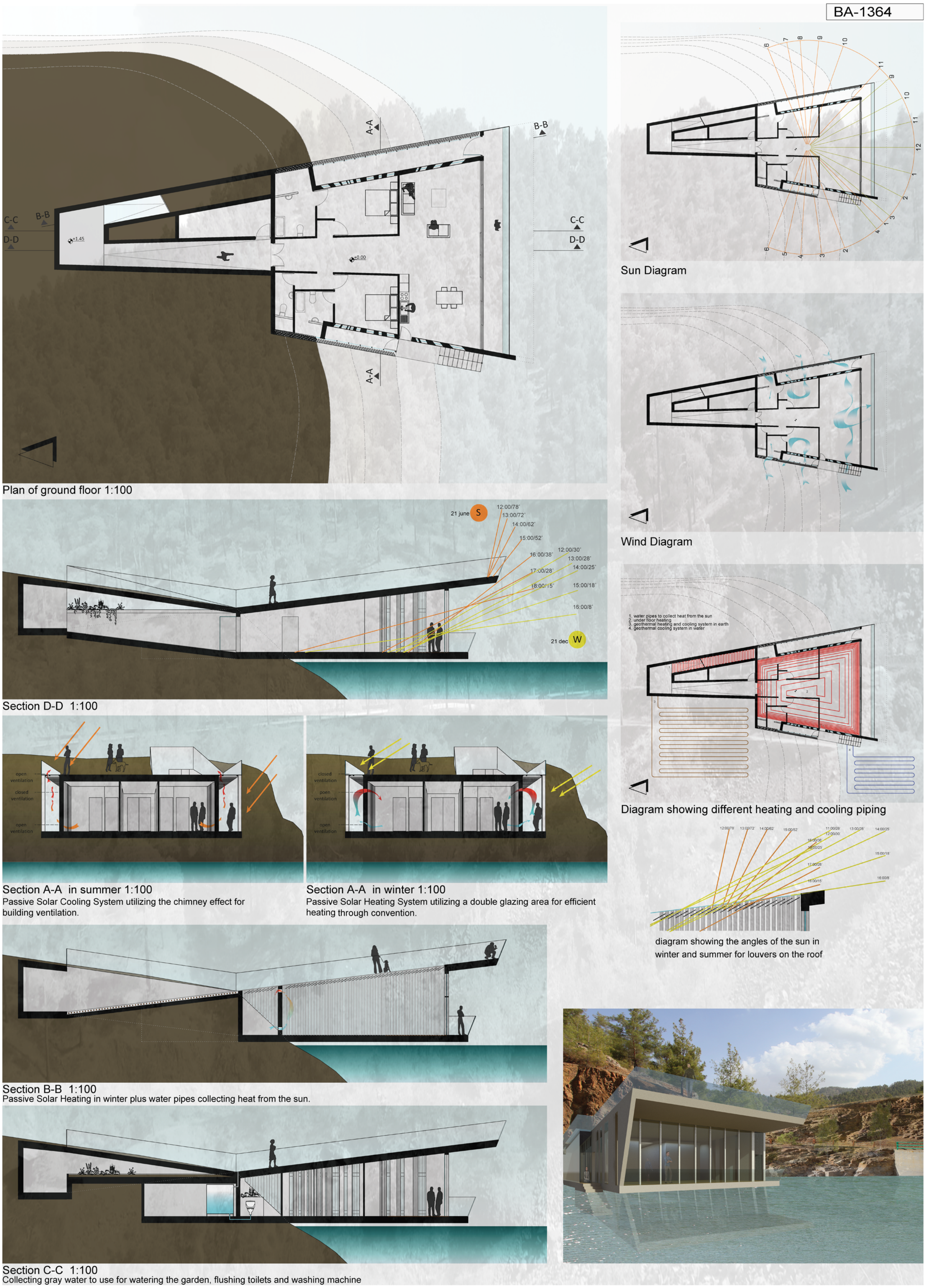
Roof Plan 1:100

21st of December at 12:00 pm

21st of December at 03:00 pm

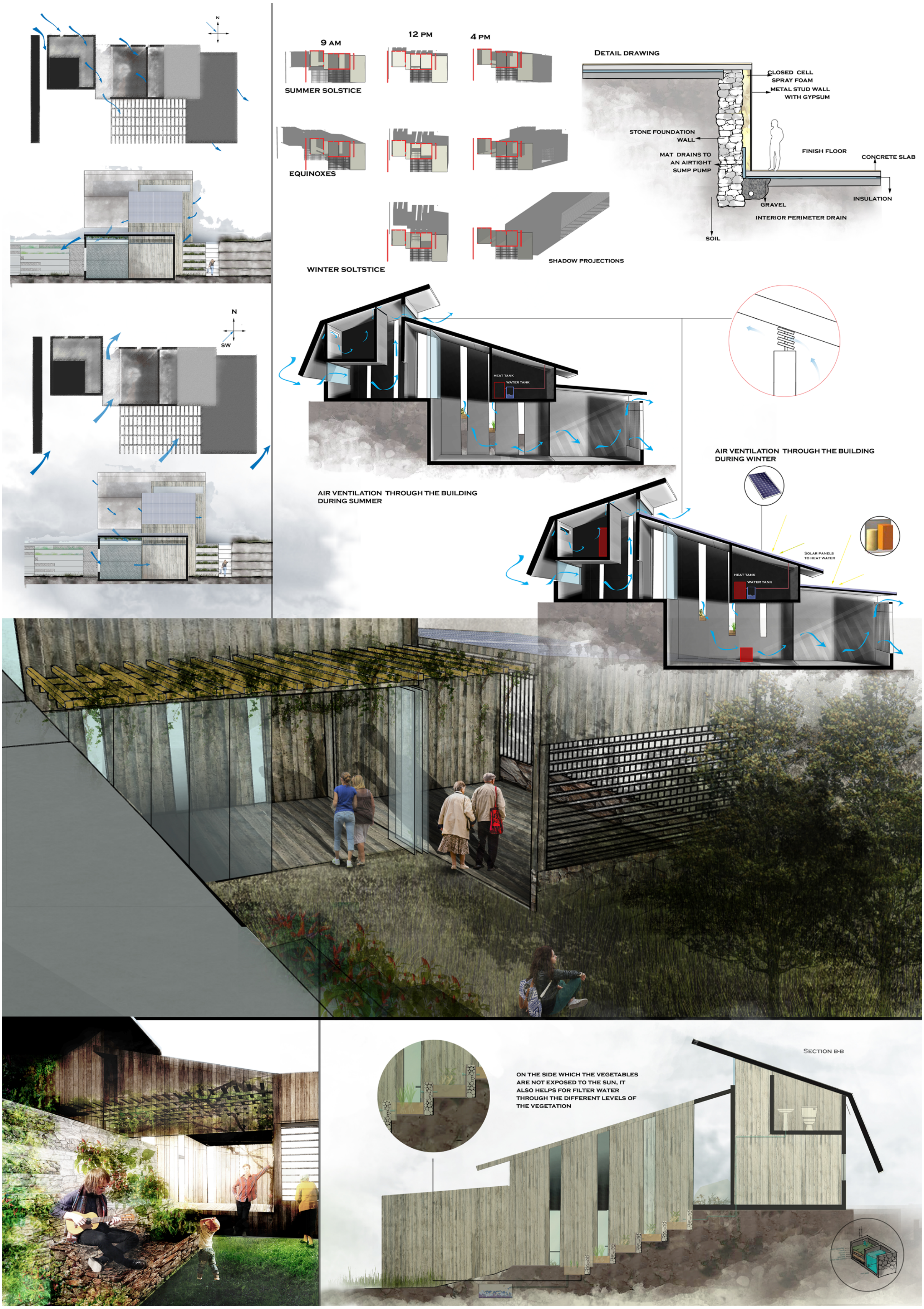
21st of June at 12:00 pm

Xyliatos Dam House. Nasim Amini, Katerina Michaelidou, Chara Andreadi, Mikaela Kotzia. 2009



Xyliatos Dam House. Nasim Amini, Katerina Michaelidou, Chara Andreadi, Mikaela Kotzia. 2009

Common Ground. Elena Siakou, Elli Mara, Christos Evagorou, Panayiotis Rotsides. 2014



Common Ground. Elena Siakou, Elli Mara, Christos Evagorou, Panayiotis Rotsides. 2014

Building Blocks for Social Sustainability Workshops

The workshop addresses the issue of social sustainability within a humanistic and cultural context, set on the platform of the built environment. Participants are called to consider matters of formal and informal urban structure, sense of community, social identity and ethics as those pertain to societal development in a diverse, multicultural setting. Operating under the premise that social sustainability can be attained through means of collaboration and common awareness, the workshop's findings aim to activate urban spaces in a three-dimensional and temporal manner in order to induce values of social and egalitarian participation (Hekkers, 2013)(Lapithis. et al. 2013).

Instructors (2013-2017): Petros Lapithis, Anna Papadopoulou, Alexandros Postekkis, Nikolas Tsaousis, Andreas Chrysochos

E-book "Building Blocks for Social Sustainability: Nicosia, Cyprus": Social sustainability extends the essence of sustainable design and combines design of the physical realm with the design of the social world in order to create successful places that promote well-being by understanding what people need from the places where they live and work. This book is a compilation of student design projects that aim to address sustainability beyond its conventional environmental component and push the boundaries of what it means for communities to thrive as part of the great infinity of civilisation.

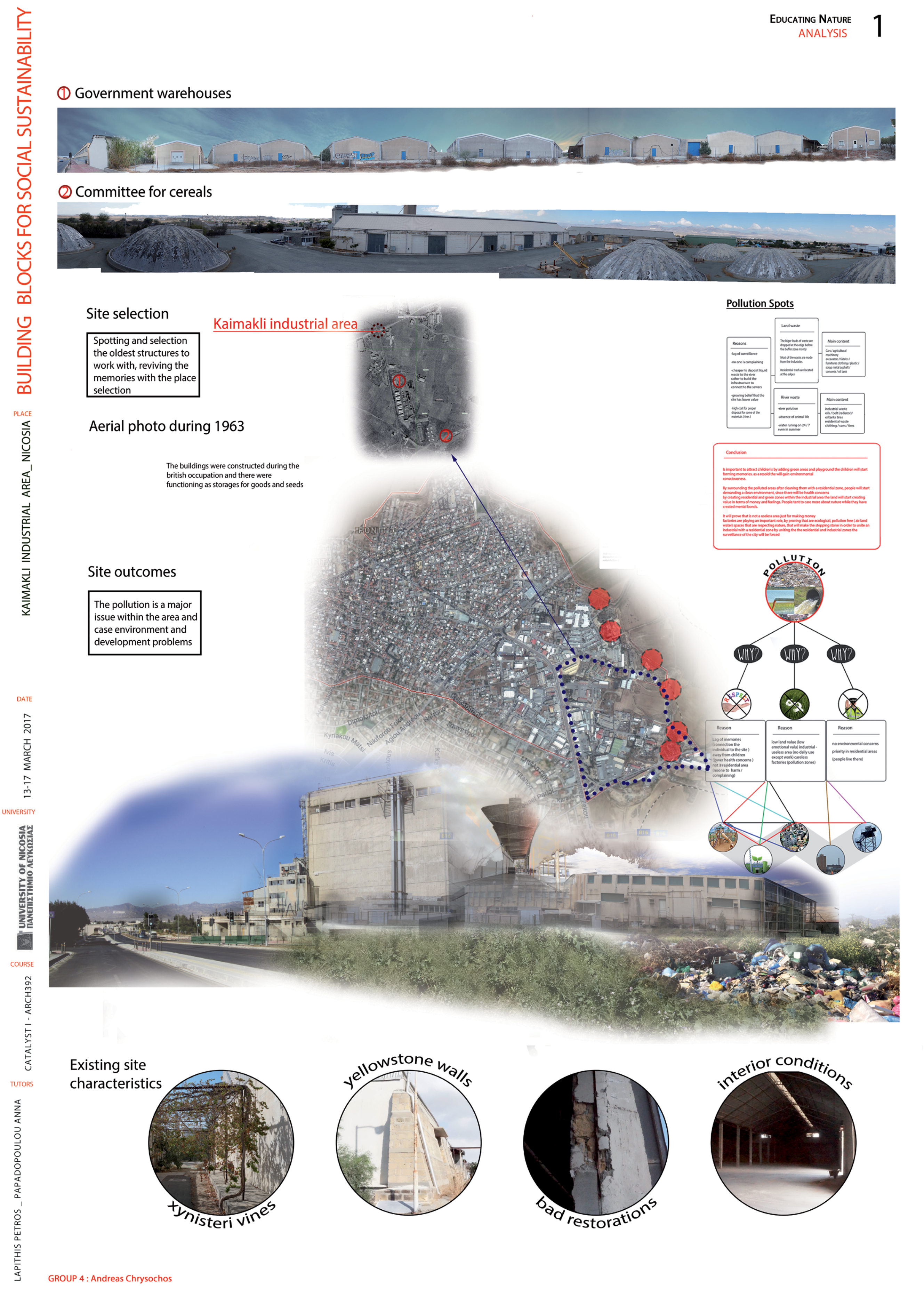
View low resolution book:

https://issuu.com/petroslapithis/docs/bbss-_v1_280dpi

Download high Resolution print:

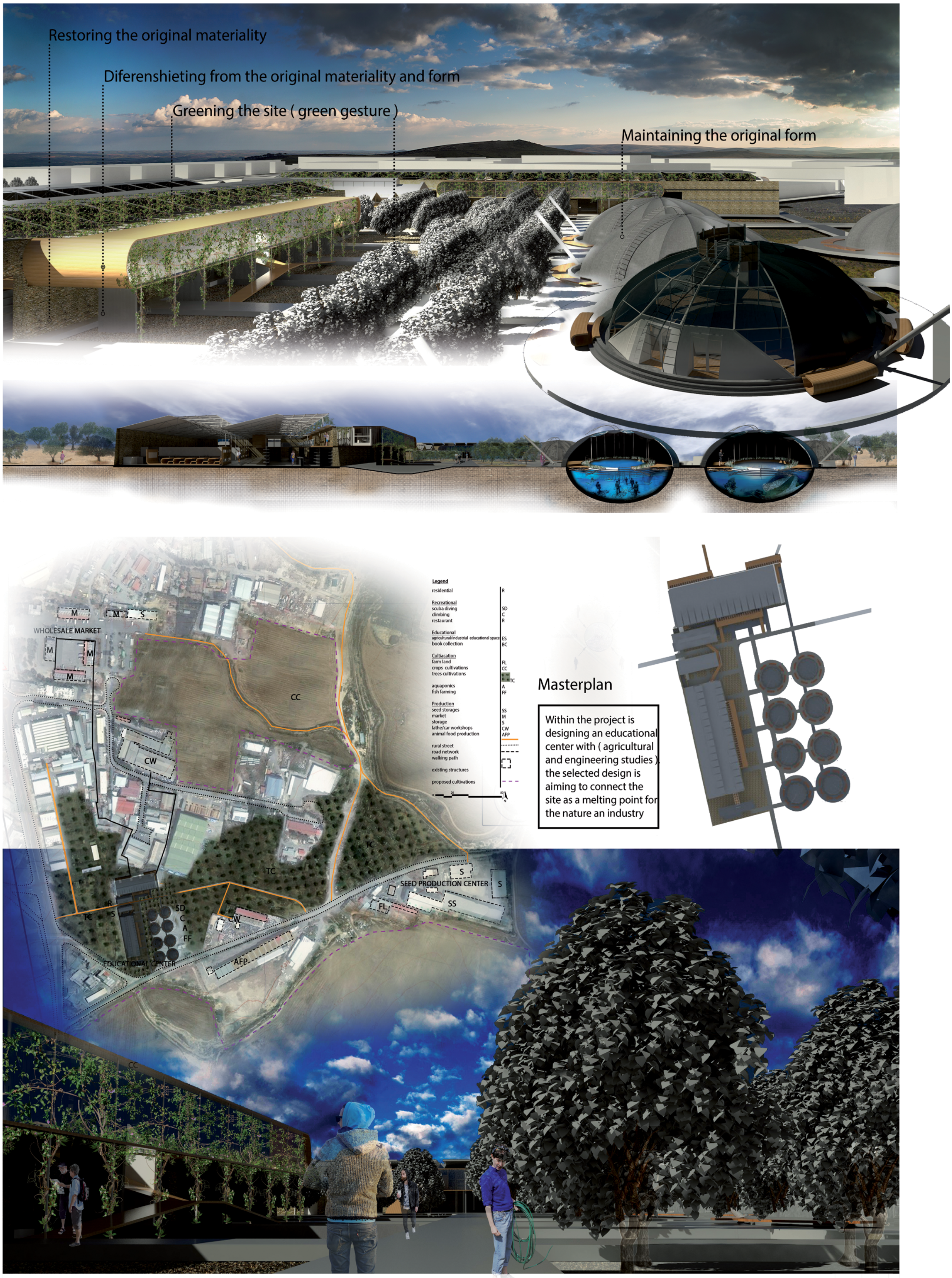
https://drive.google.com/open?id=0BxPGSTtY7O2SUVgwaVNOMno0SE0

Industrial Upcycle. Kaimakli Industrial Area. Louis Agamemnonos, Anastasia Iliaki, Ivi Nikiforou. 2017



Educating Nature. Kaimakli Industrial Area. Andreas Chrysochos. 2017

EDUATING NATURE
DESIGN PROPOSAL
2



Educating Nature. Kaimakli Industrial Area. Andreas Chrysochos. 2017

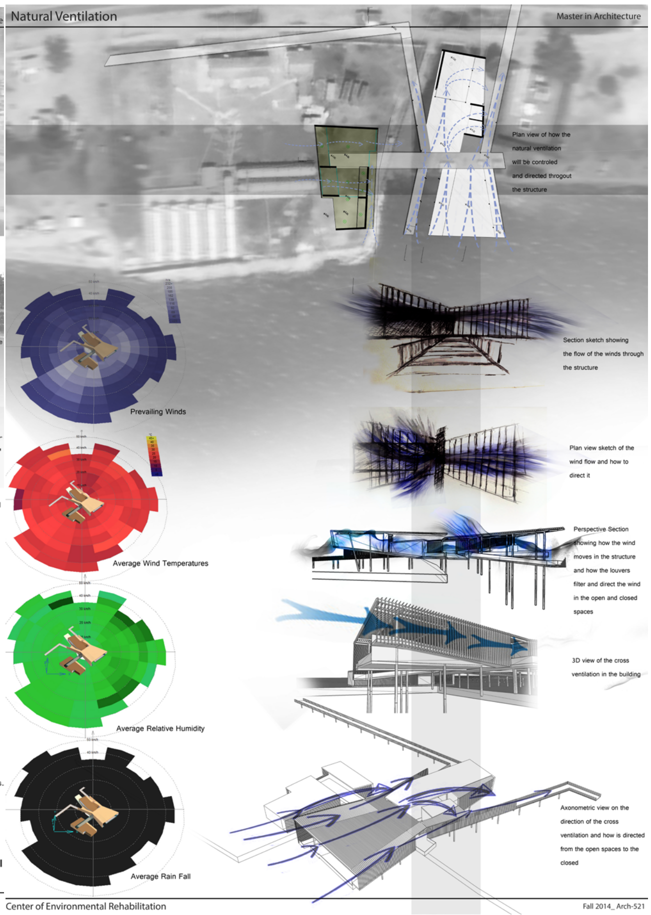
Multifunctional Temporality. Agios Mamas Refugee Estates. Georgia Adamou, Ourania Apserou. 2014

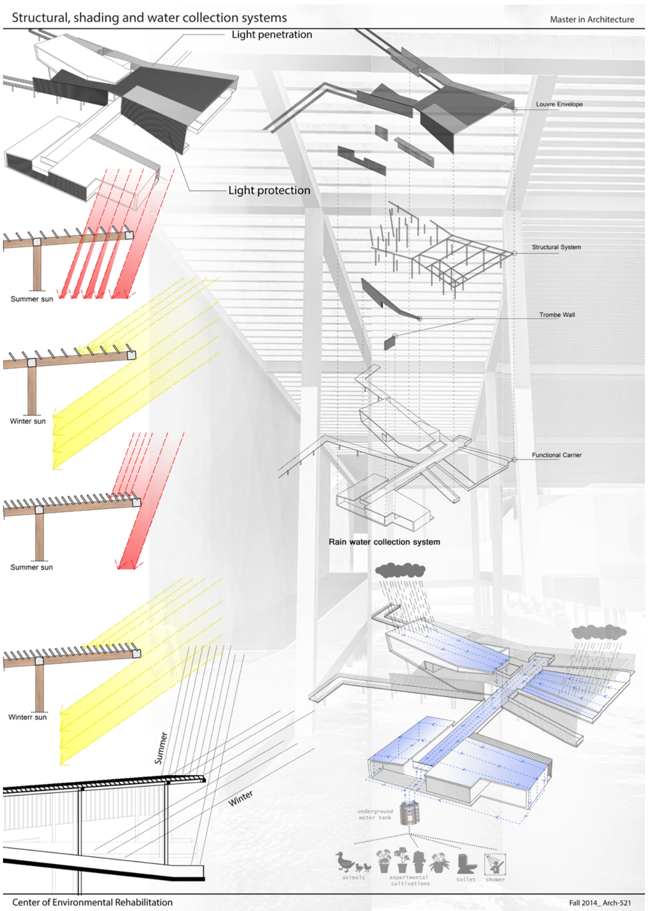
Multifunctional Temporality. Agios Mamas Refugee Estates. Georgia Adamou, Ourania Apserou. 2014

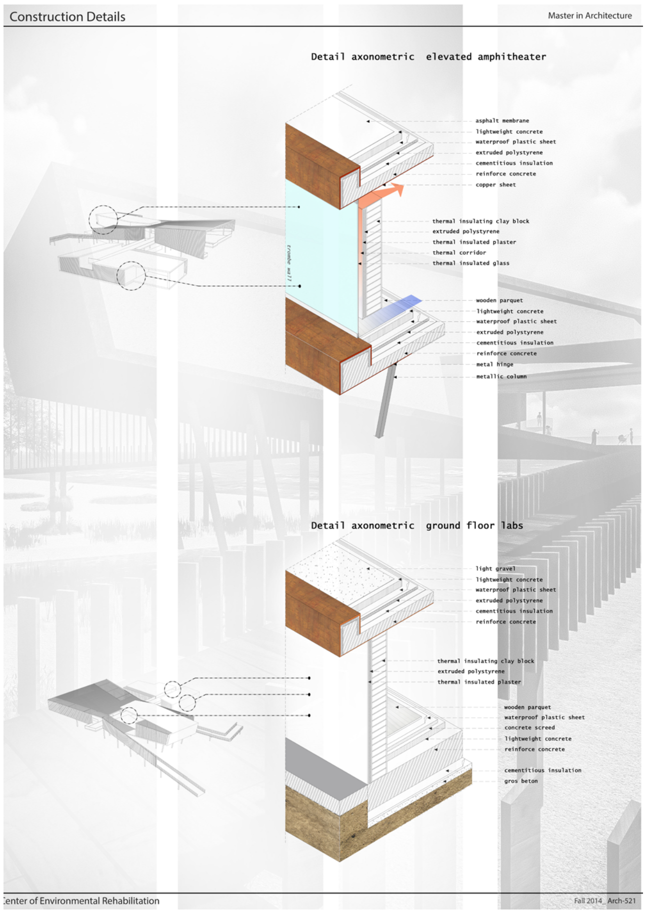
Bioclimatic Architecture Course

This course introduces the principles underlying bioclimatic architecture and environmental modification. The relationship between climate and architecture are traced back to historic examples of vernacular bioclimatic architecture in order to provide an appreciation of established passive environmental strategies and systems. Discussions on contemporary theory dealing with issues of sustainability and the performance of buildings will mature into critical personalised positions. In parallel to readings, students explore seminal case studies in order to develop an analytical capability and a vocabulary of contemporary bioclimatic architecture. This overview hence deals with a wide range of topics; from understanding climatic data and human comfort, to basic passive heating/cooling strategies, to more complex autonomous/living systems, to introducing building energy performance software as a tool. The objective is to develop an awareness on how materials, techniques in structure, construction and environmental modification are integrated in the generation and realisation of bioclimatic architectural designs.

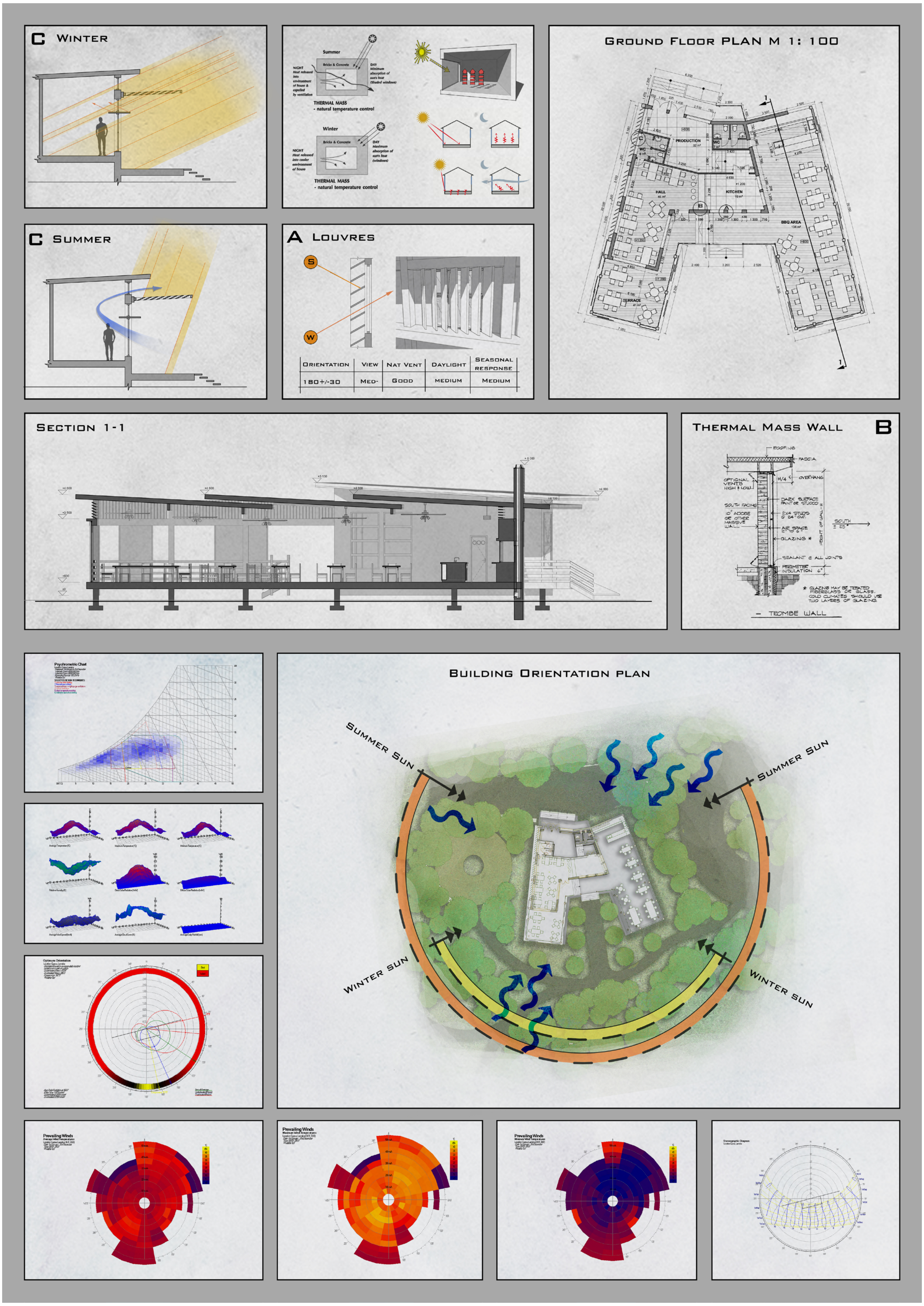
Instructor (2015-2018): Petros Lapithis







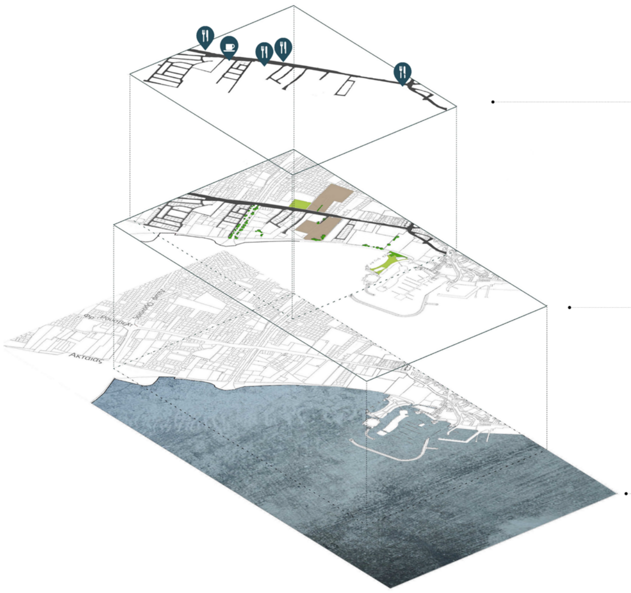
Centre for Environmental Rehabilitation. Alexandros Postekkis, Yiannis Theodotou. 2014



BBQ Restaurant. Egor Mosolov. 2014

Restaurant. Egor Mosolov. 2014

SITE ANALYSIS



NEIGBOURHOOD : COMPETITION AND ACCESS

The proposal for a fish/barbecue restaurant has mulitple goals. First of all, the lack restaurants and/or cafés near the old port has made it an unpopuar destination for tourists. Restaurants and cafés can be found on the main road and nowhere near the coastline. By implementing a restaurant that links the surroundings to the cultural and economical history of Limassol, an attempt can be made to make the site a more visited place by tourists or inhabitants of Limassol. Second, the access to the site on the coast is open which makes the restaurant easy to reach for both clients and deliveries.

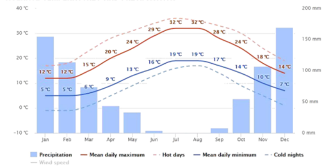
INDUSTRIAL SITE OF CARNAYO

"Carnayo" is how the zone between the old and the new ports of Lemesos (Limassol), is locally called; a highly provocative area in terms of location, history and heritage and also in terms of its existing structures, landscapes and images. The former industrial zone covers the west coastline of Limassol, which spreads between the two ports of the city, the Harbour (Old Port) and the New Port. The area has an elongated rectangular shape with an average length of two kilometers and an average width of 500 meters. The area is located southern of Franklinou Roosevelt Avenue, eastern of Omonias Avenue and western of Kioporoulouzante and Celal Mazar streets. The under construction Limassol Marina is located on the eastern edge of the study area.

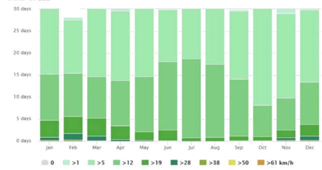
OLD HARBOUR OF LIMASSOL

The overall site is located on the coastline of the old port of Limassol. LImassol is one of the six cities of Cyprus; it is a seaside city. It's quite an interesting city, with regards to its built environment. The city hosts the main port of the island as well as the headquarters of several multi-purpose trade, economy, tourism and other industries. The industrial capital of the city was gradually developed and influenced its development. The industrial buildings combined with the port's activities play a vital role in the mixed character of the contemporary city, which has also been greatly influenced throughout the centuries, in accordance to its alternating functions and uses.

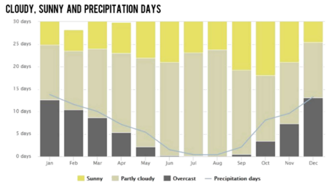
AVERAGE TEMPERATURES AND PRECIPITATION



WIND SPEED



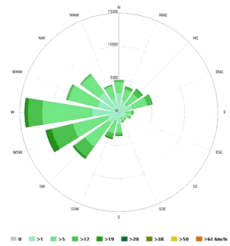
CLOUDY, SUNNY AND PRECIPITATION DAYS



PROJECT LOCATION

Limassol has a Subtropical-Mediterranean climate with warm to hot and dry summers and very mild winters, which are separated by short springs and autumns which are generally warm and pleasant. From December to March the weather is unsettled and can be rainy and windy but you can also often expect great amounts of sunshine averaging around 6 hours a day.

WIND ROSE DIAGRAM



INTERIOR ORGANISATION AND DESIGN

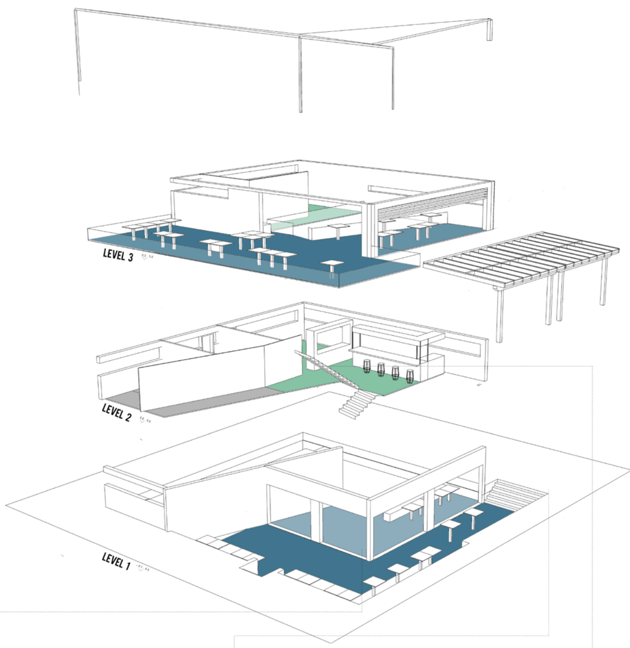
DOWNSTAIRS AREA
(- 1 . 0 0m and 0 0 . 0 0m)

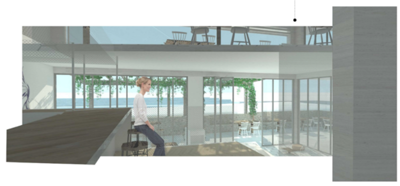
outside, covered terrace seating area
inside lounge area
inside seating area
vestiare

bar
kitchen
kitchen provisions and cold storage
restrooms
outside barbecue area

UPSTAIRS AREA
(2 . 5 0 m)

Inside seating area
outside, covered seating area
staff provisions
office





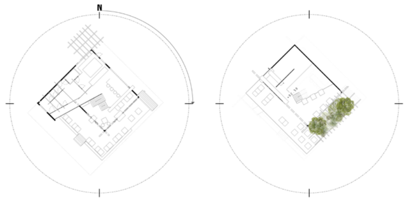
Carnayio Restaurant. Birthe Geerkens. 2016

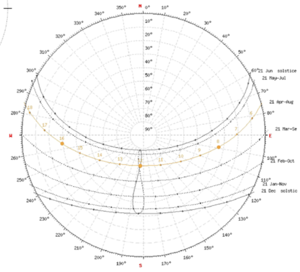
PASSIVE SOLAR DESIGN: SUNPATH

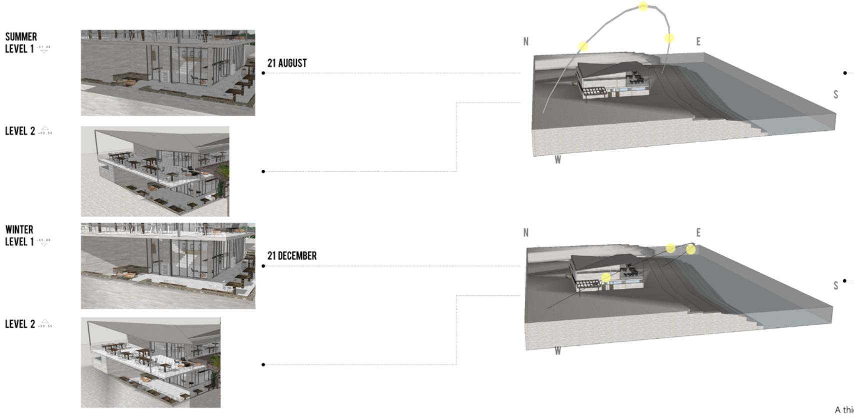
Passive solar design refers to the use of the suns energy for the heating and cooling of living spaces.
In this approach, the building itself or some element of it takes advantage of natural energy characteristics in materials and air created by exposure to the sun.
The most effective designs are based on specific understanding of a building site's wind patterns, terrain, vegetation and solar exposure or "sunpath".

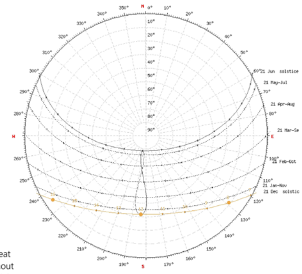
The orientation of the restaurant ensures daylight at any given moment of the day, during winter and summer. Kitchen, toilets and provision area are located on the north and north-west side of the building. Seating area is located from east to west, spread out over different levels that provide different views over the coastline and different kinds of sun throughout the day and the year.

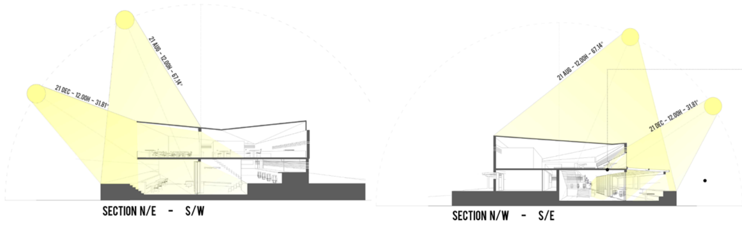
Thermal mass is ideally placed within the building and situated where it still can be exposed to low-angle winter sunlight (via windows) but insulated from heat loss.
In summer the same thermal mass is obscured from higher-angle summer sunlight in order to prevent overheating of the structure.









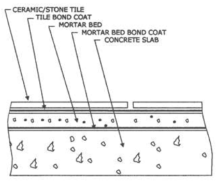


SECTION N/E - S/W

SECTION N/W - S/E

A thick concrete floor will conduct heat and store it relatively evenly throughout the floor (though areas directly struck by the sun will be warmer).
Even though wood would be a better solution for this kind of project (recycled wood from shipwrecks, more environmentalfriendly and fitting with the design), a wood floor will not distribute heat well, because although wood has high thermal mass, it does not conduct heat well.

Materials such as ceramic floor tiles or brick make better choices for covering a direct gain slab. Tiles should are attached to the slab with a mortar adhesive and grouted with complete contact to the slab--this ensures good heat conduction.

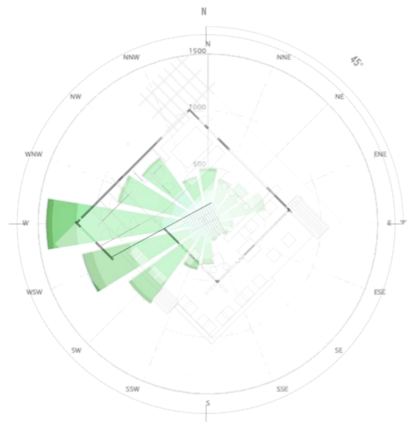


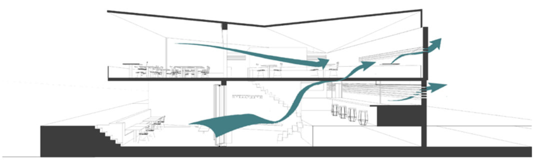
NATURAL VENTILATION

Natural ventilation, also called passive ventilation, uses natural outside air movement and pressure differences to both passively cool and ventilate a building. The restaurant has large, movable windows that can serve as ventilation openings as pleased. These tall windows with openings at top and bottom can use convection as well as outside breezes to pull hot air out the top of the room while supplying cool air at the bottom.

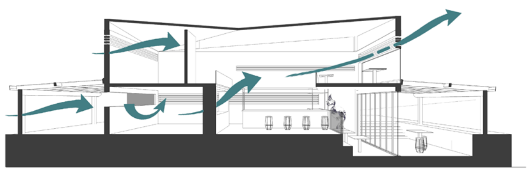
The long horizontal strip windows on the north and east side of the building will ventilate the space more evenly. Because of the large open space above the bar the hot air will be able to go up and dissapear through the windows that are located higher.

For buildings that feature a courtyard and are located in climates where cooling is desired, orienting the courtyard 45 degrees from the prevailing wind maximizes wind in the courtyard and cross ventilation through the building. Since the prevailing wind in Limassol comes mainly from the west side, the building has been turned 45 degrees to have maximum profit of the natural ventilation.

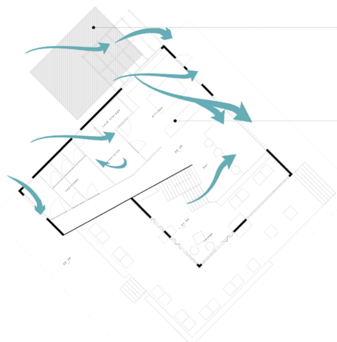




SECTION N/E - S/W



SECTION N/W - S/E



The fumes of the grill area will be directed to go past the building envelope

Any remaining smells from the barbecue or the kitchen (raw fish) will be sucked out of the building through the horizontal window, without passing the customers.

Carnayio Restaurant. Birthe Geerkens. 2016

Energy Efficient Buildings Course

This course aims to create resource-efficient structures that are comfortable and healthy. Energy Efficient design ensures that the impacts associated with resources are kept to a minimum while also considering issues of energy management, light, temperature, air quality and psychological aspects of structures that affect health. This course focuses minimising non-renewable resource use, while considering the need to create healthy environments. Topics addressed include envelope design, energy use and production, alternative energy sources and indoor/outdoor environmental quality.

Instructor (2015-2017): Petros Lapithis

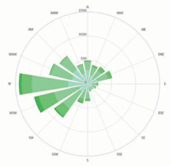
Site Analysis

ANALYSIS

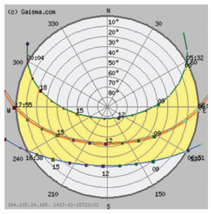
The site analysis of this project was done in Kaimakli Industrial Area, Nicosia. The investigation was done on the existing non energy efficient building in Sopaz area.The chosen site is a storing grain area that is not working anymore, which needs environmental restoration because of its previous industrial use. The main street branches into a secondary street which passes infront of the entrance. Cars and pedestrian can access this area.nThis secondary street lead to the industrial area and waste land.

Entrance Greenery Pedestrian

Rose Wind



Sun Path



Cracks in the concrete cladding (main structure stone)
Some concrete pieces are falling from the columns.

Uneven flooring with cracks
Poor natural lighting quality and poor ventilation
Roof (no thermal insulation for corrugated steel)

Unorganized greenery

Cracked envelope,
No openings for natural light
No ventilation
Rusted stairs (not secure)

Uncovered Electric Cables
Rustic and uncovered water pipes
No Shading

Doors (nonfunctional/old/unusable/closed by wood)
Windows (rustic windows metal frame)

Openings between walls and ceiling

Problems to solve

#	Location	Issues	Considerations	Solutions	Images
1	Building A	Zig-zag crack in the concrete cladding(main structure stone)		-Close the concrete opening	
2	(B) Between Buildings	-uncovered electric cables -water pipes	-Safety/organized/ Space - uncovered/rusted	-Cover them safely -Integrate the cover with the design -change them and cover them	
3	Building A	-column cracks, some parts are falling	-low footprint	-Add a metal structure To anchor the coloumns	
4	Building A	-poor natural lighting quality	-glare	-add windows /south -shading/louvers	
5	Building A	-poor ventilation	-direction	-air exchanger -stack effect -solar chimney -openings -HVAC	
6	Building A	- Wall concrete cladding is falling		-remove all concrete cladding -restore the stone structure	
7	Building A	-flooring (cracks/uneven/rough)	-walkable -nonsleeper	-change surface	
8	Building A	-no artificial light	-energy consumption	-add lighting systems -works on BMS	
9	Building A	-Doors (nonfunctional/old/unusable/ closed by wood panels)	-Functional	-change the doors	
10	Building A	-Windows (rustic windows metal frame)	-No shading	-Add louvers(solar panels) -change the metal frames	
11	Building A	-Roof (no thermal insulation for corrugated steel/no insulation at all)	-sustainable insulation (sound, water, heat....)	-Add thermal insulation -change the roof -add solar panels	

#	Location	Issues	Considerations	Solutions	Images
12	Building A	-Walls(no insulation)	-sustainability -water penetration -durability	-add accoustic insulation -add thermal insulation	
13	Building A	-Opening between the walls and the ceiling(unwanted water and wind penetration)	- sustainable penetration (no water , no wind)	Change the ceiling and close the openings	
14	Building A	-Unorganized greenery around the buildings		-organize the greenery	
15	Building A	-Cooling and heating	-healthy and sustainable mechanical system	-geothermal system -solar panels -Trombe wall	
16	Building A	-Open water pipes		-change the water pipes	
17	(D) Dome	-Rusting machines		-remove the machines	
18	(D) Dome	-Change the outer layer		-change it	
19	(D) Dome	-No openings for natural light	-glare -direction	-add openings for wind	
20	(D) Dome	-No ventilation	-direction	-air exchanger -openings	
21	(D) Dome	-Rusted stairs (not secure)	-	-change the stairs	
22	(B) Between buildings	-no shading	-	-add shading systems (louvers, canopy)	

Analysis of an abandoned industrial warehouse. Aya El Messelmani, Fatina Eless. 2017

Introduction

Concept

Design a sustainable building, an activities center that include kids activities, painting workshop, physical exercise space and library.

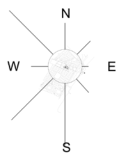
Each space design based on the activity that takes place as well as the metabolic rates. The orientation and the shape of the spaces are design according sun path and wind diagrams in order to be bioclimatic and then with integrated systems become energy efficient building.

Building Features

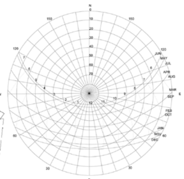
1) Sun / Shading
2) Ventilation
3) Solar Chimney
4) Photovoltaic panels
5) Geothermal Heat pump
6) Thermal insulation
7) Green roof
8) Building Management System
9) Materials

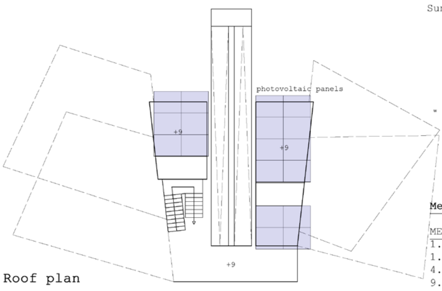
Photos of the area

Wind diagram



Sun path diagram



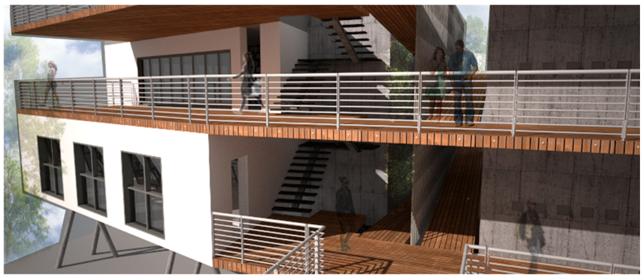


Roof plan

Metabolic rates in each space

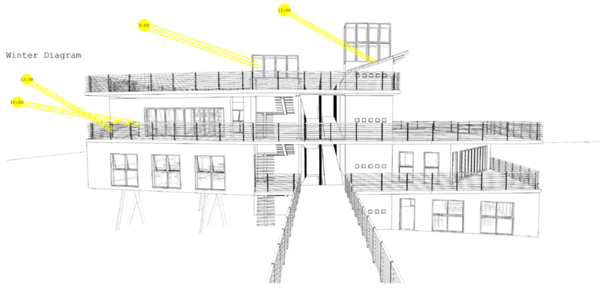
MET
1.0 :Painting workshop
1.0 :Library
4.0 :Kids activities
9.5 :Physical exercises space

Renders

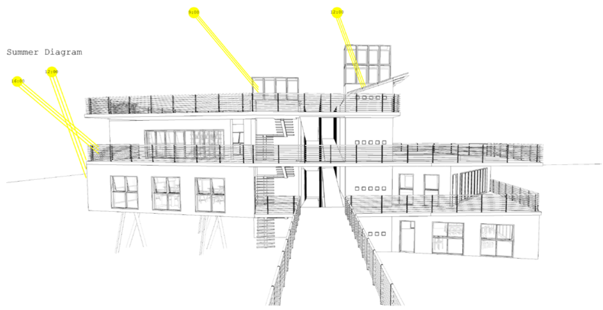


Sun

Winter Diagram

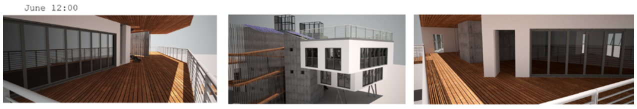


Summer Diagram

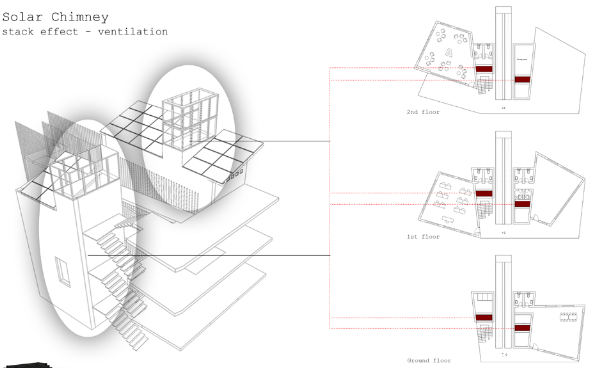


December 12:00

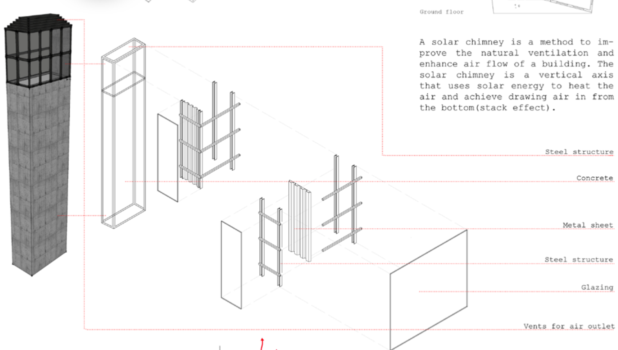
June 12:00



Solar Chimney
stack effect - ventilation

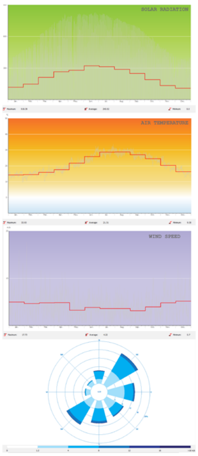


A solar chimney is a method to improve the natural ventilation and enhance air flow of a building. The solar chimney is a vertical axis that uses solar energy to heat the air and achieve drawing air in from the bottom(stack effect).



The suction of the air achieved through sun exposure, the heat and the materials that solar chimney is made of. The bottom of solar chimneys are made of concrete until the roof level and the above part is metal structure covered with glass. On South side there is a metal sheet, material with high thermal mass, that enhance the heat.
The sun heats up the metal sheet and the air, the high temperature cause the air suction from the spaces.

Activities Center. Maria Georgiou. 2015



Land plot

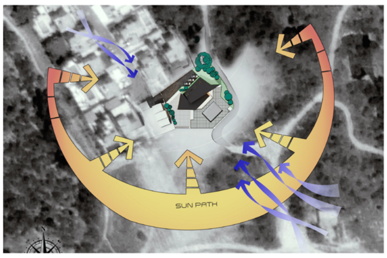
For my project I have chosen a site located near Protaras, 300 meters from the Konnos Bay. The site's geographical position is 34°59'13.61"C, 34° 4'22.97"B. It is situated at a high sea coast with the height above the sea level is 18 meters. From the south, the site is adjacent to a steep cliffy sea shore, while on the eastern side the shore line gradually descends to the sea level. The place can be reached by the Kavo Greko Road, which approaches the site on its western side. Also in the west, the plot is adjacent to a group of houses, meaning that the area has all the required utility connections, which will allow us to minimize the building cost by using the existing road and utility connections. Protaras is situated to the north-west from the site. The south-eastern direction provides a beautiful panoramic view of the sea.
The area of the site is 2 000 m2
There is a natural promenade path between the site and the sea.

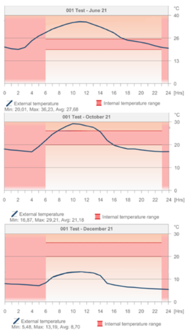
Climatic conditions

The chosen area has average weather conditions similar to those of the southern coastal line of Cyprus. In particular, the hot season lasts from June to September with, on average, July is the warmest month and January is the coolest month. Most rainfalls are seen in October, while dry period is usually from April to July.

The main climatic features of the site area are as follows:

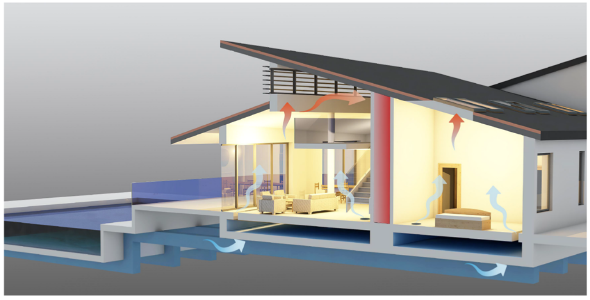
1. Average temperatures range from around 33°C in summer to around 8°C in winter.
2. Average monthly wind speed stays fairly stable at around 4.2 meters per second from December to September and falls to around 3.3 metres per second in October and November.
3. Average monthly humidity ranges from around 80% in winter to just over 50% in summer.
4. Average monthly hours of sunshine increase from around 180 in January to around 380 in July.

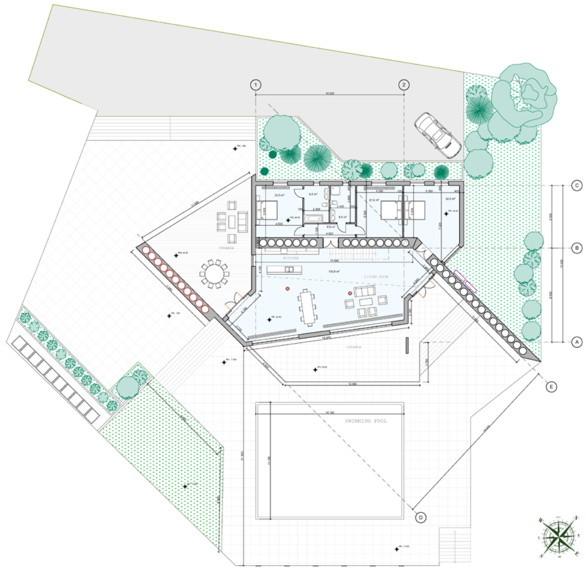


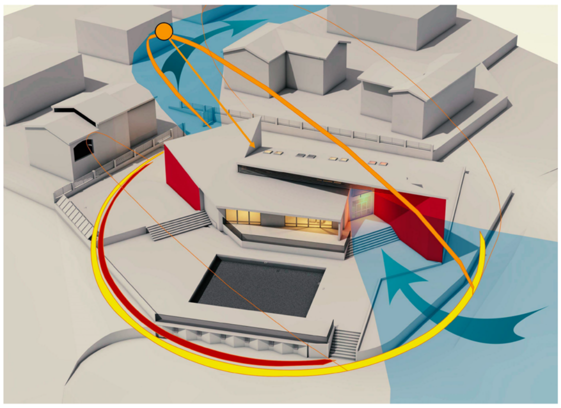


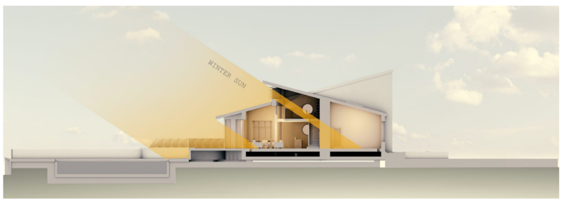
Stack effect

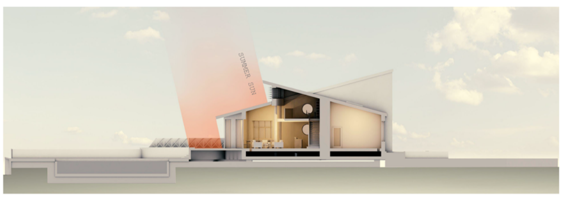
Warmer air is less dense and more buoyant. This means that warm air has a tendency to rise. This stack effect, also referred to as the "chimney effect", is used to naturally ventilate buildings. Cooler outside air is drawn into buildings at a lower level, where it gets warmed and then rises through the building to vent out at a higher level. At that, a positive pressure area is created at the top of a building and a negative pressure area at the bottom. Stack ventilation <http://www.designingbuildings.co.uk/wiki/Stack_ventilation> does not require mechanical assistance, it can be maintained by simply introducing openings at the bottom and the top of buildings. How intensive the process would be depends on a number of conditions, including the area of the openings, the height of the stack, the difference of the temperature at the bottom and the top of the stack, as well as the pressure differences outside the building.
In my project, this effect is used as part of the windcatcher technology. The stack effect makes air coming from underground channels to the basement move higher into the house, where it is used and then removed through the railings under the ceiling in the living space. In the bedrooms, the stack effect also helps to move cooler air from the basement and then remove the warm air through the roof windows.











Architecture and planning solutions

The main premises of the house are grouped on both sides of the massive central wall that separates the living space and the bedroom area.

The living space combines the sitting and dining areas as well as the kitchen on the ground level and the working area on the shelf deck. From the sitting area you can get to the partially covered veranda adjacent to the house on the south-eastern side and to the patio protected from the sun by the roof extension on the western side.

The house has three bedrooms looking to the north-west. All the bedrooms are equipped with roof windows.
Under all the premises, the building has a basement, equipped with a system of air delivery pipes, which supply warm and cool air allowing the house to maintain and regulate inside microclimate.

Sustainable Single Family House. Egor Mosolov. 2016

Sustainable Design Unit Studios

In 2009, the SDU Studio was titled Exploring Dimensions of Slow Life Filtered through Sustainable Design and its purpose was to investigate and juxtapose qualities associated with the Slow Life Movement and the principles of sustainable design and bioclimatic architecture.

By 2011, it was deemed necessary to revisit the thematic parameters of the studio course and it was decided that the issue of quality of life was to replace the Slow Life Movement. This change was mostly in response to students' interests, as those were observed by the instructing team. The studio title became Exploring Dimensions of Quality of Life through Sustainable Design. The same thematic was maintained in the following year.

In 2013, however, as a direct response to the financial crisis that impacted Cyprus in March 2013 and led to an array of on-going socioeconomic concerns, the studio thematic veered towards addressing issues of environmental and social sustainability. Its title became Exploring Dimensions of Environmental and Social Sustainability.

In 2015 the unit again changed its thematic to Design for Diversity: Voice vs Vision. The unit considers notions of diversity within an academic environment and explores their significance in challenging boundaries that enable architectural design to act as an advocate for racial, gender and class equality. In setting a framework of social systems that facilitate ecological cities, focus is set on juxtaposing two concepts: vision and voice. The term 'vision' is the province of a single person, acting on his and (less frequently) her own accord, whereas 'voice' refers to collective, collaborative efforts.

Coordinator (2009-2018): Petros Lapithis

Instructors (2009-2018): Petros Lapithis, Anna Papadopoulou, Alkis Dikaios, Eleonore Zippelius, Tonia Sophokleous Lemonari, Zenon Sierepeklis, Adonis Kleanthous, Dimitry Sklyaruk

E-book "Designing a Difference -Social Sustainability in Cyprus": An academic e-book compiled of student projects from the Architecture Department of University of Nicosia on social sustainability in Cyprus is now available on-line. Edited by academics Petros Lapithis and Anna Papadopoulou and journalist Melissa Hekkers, the book brings to local case studies to the forefront in an attempt to give a concrete understanding on social sustainability and architectural practices. The goal of this book is to transfer knowledge without any monetary benefit. The book is available for free.

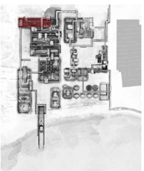
View low resolution book:

https://issuu.com/petroslapithis/docs/designing_a_difference_-social_sust/1

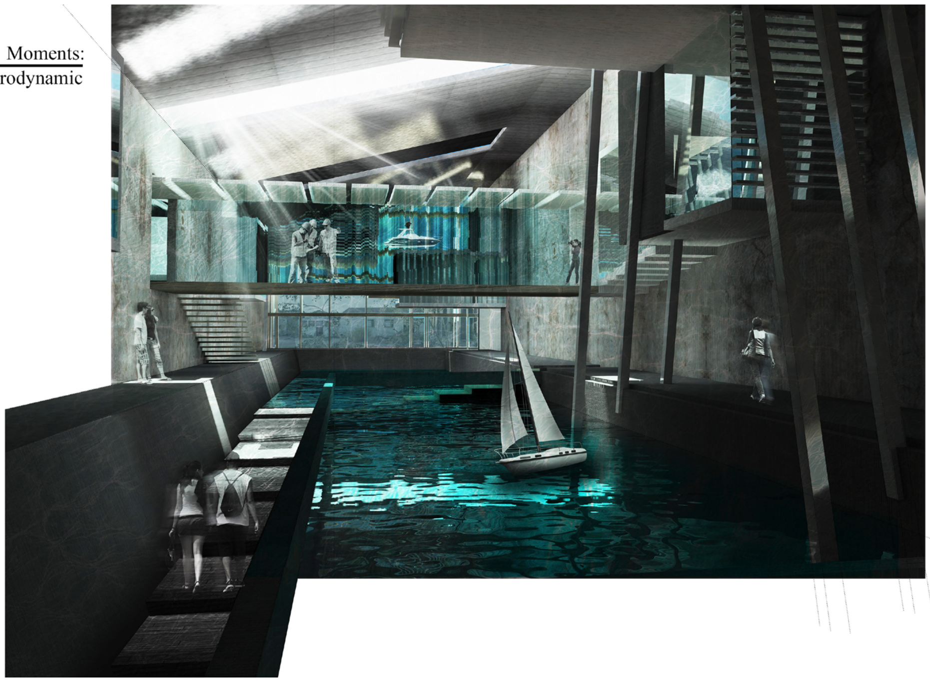
Download high Resolution print:

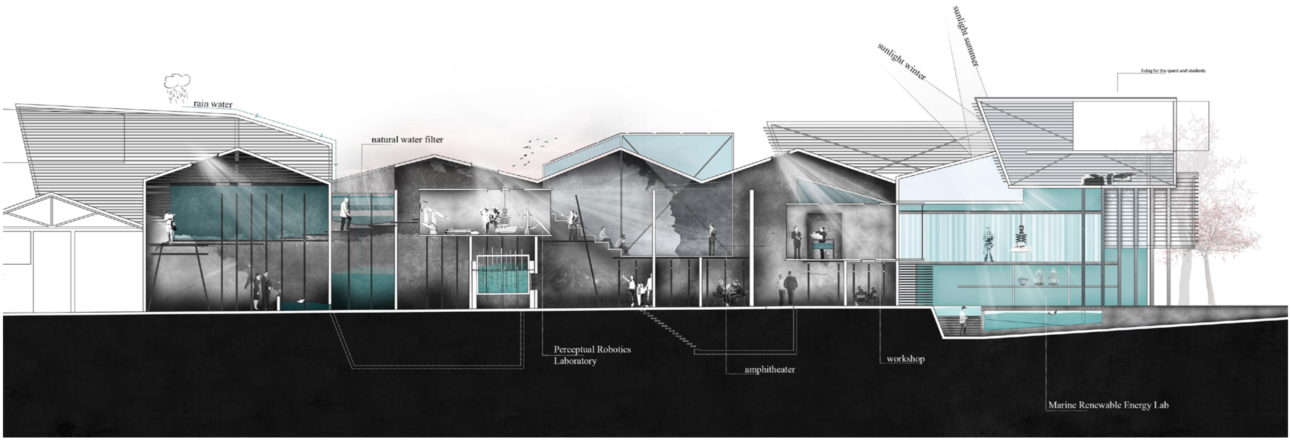
https://drive.google.com/open?id=0B9m9oHBfzmmlQ1FnRDZFa2NBNVE

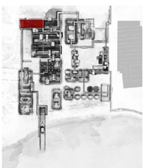
Moments:
Kelvin Hydrodynamic



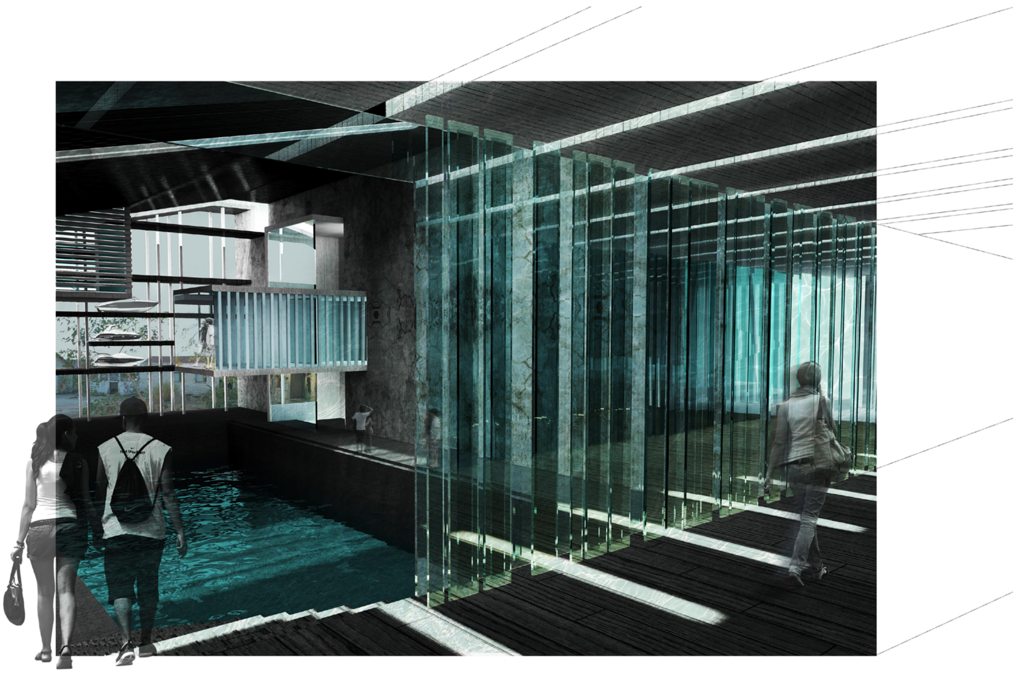
This moment represents a part of the Laboratories, more specifically the Kelvin Hydrodynamic, where the marine architects are doing different testing of models. Can be observed the experiential path, pass through from the pools (when they do testings), In addition the experiential pass is on the "eyes" level, so the passers can observe the machines of the waves.



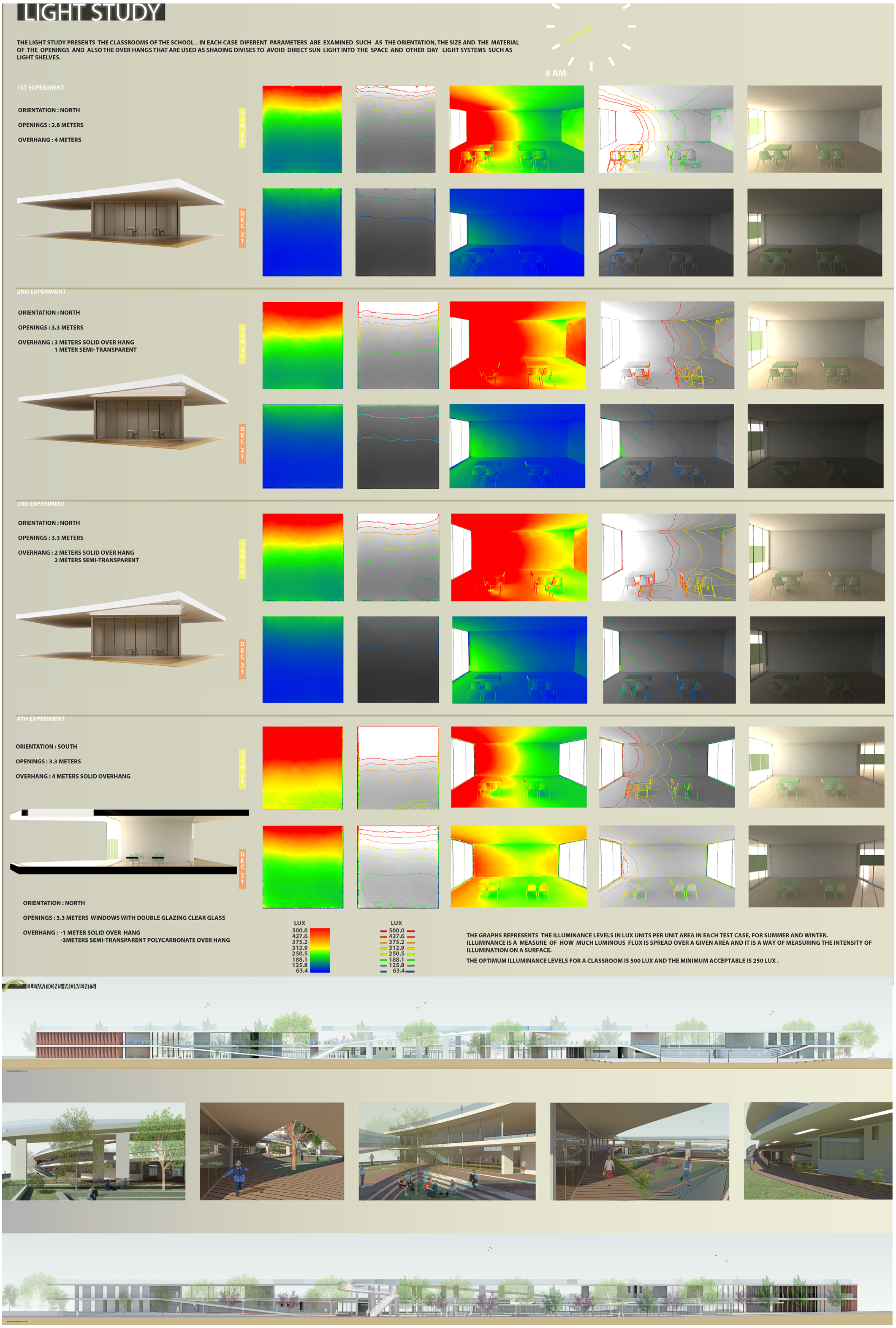




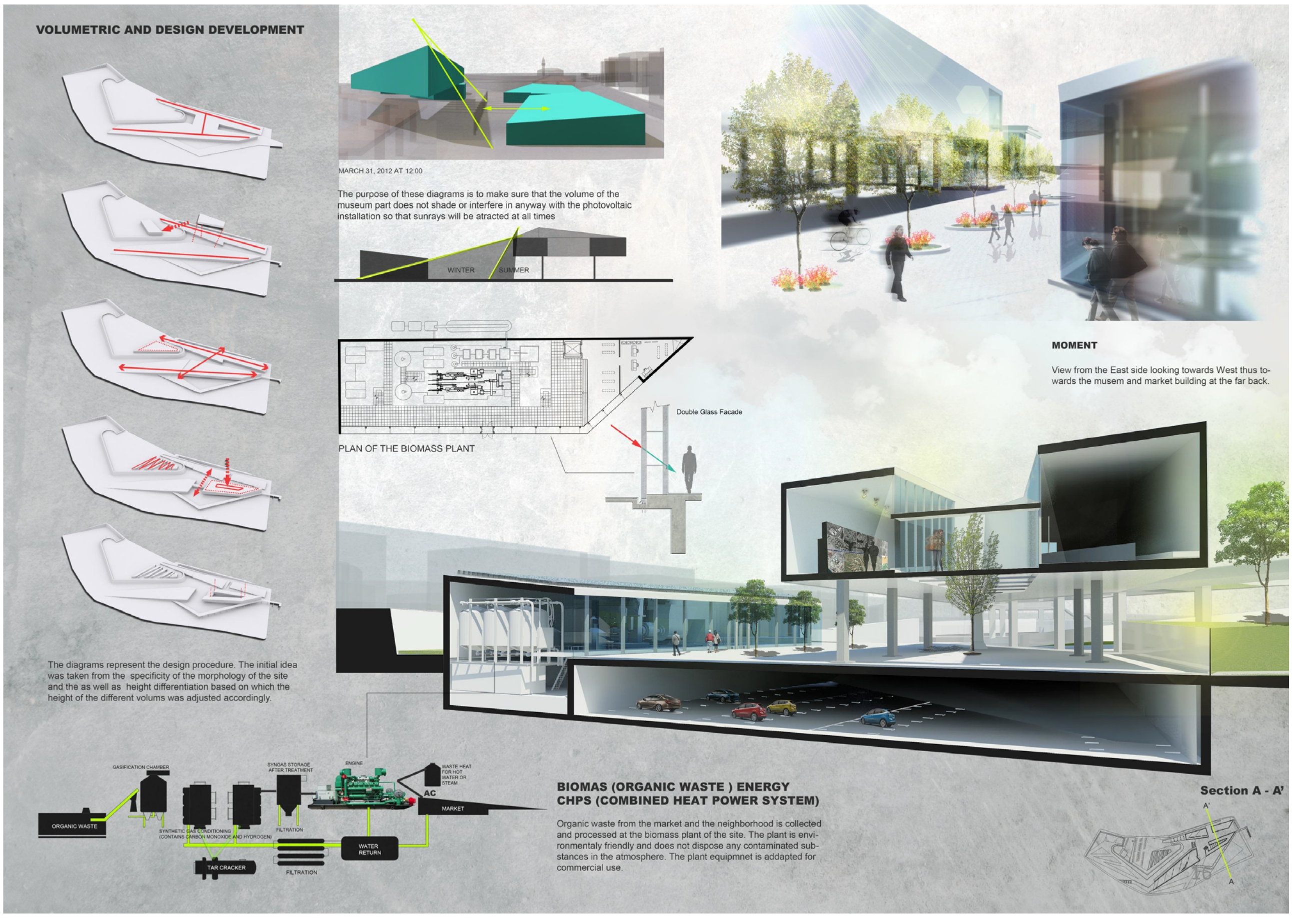
At this moment the experiential path is shown in zoom in. In depth of the moment can be observed the new space on level. in relation with oldspace. At this existing building the existing facade has been removed and it was replaced with glass and shelves for the models. So with this way passers can be observed a small part of the labs.

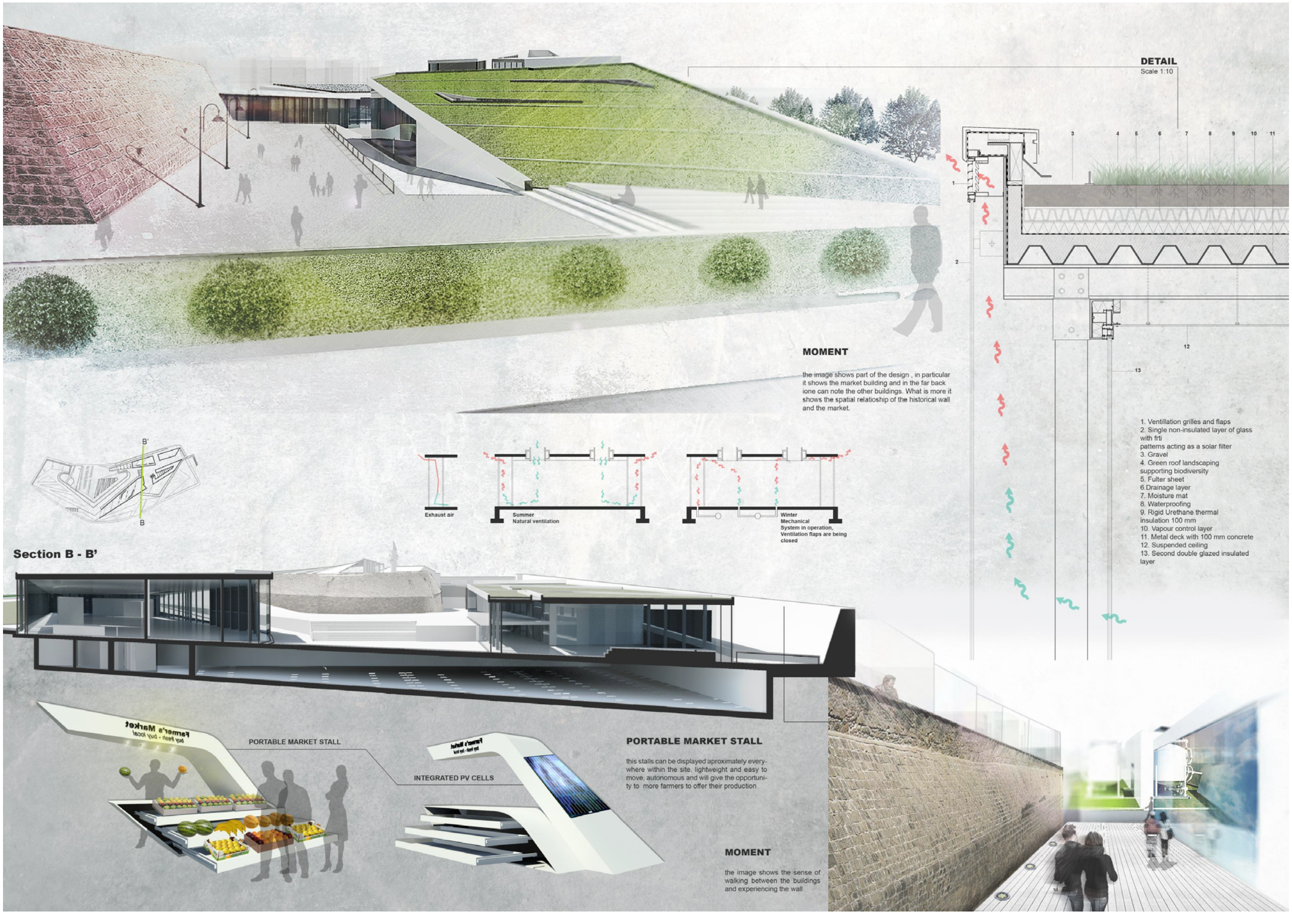


Marine Engineering University. SODAP building Carnayio. Christina Demetriou. 2016

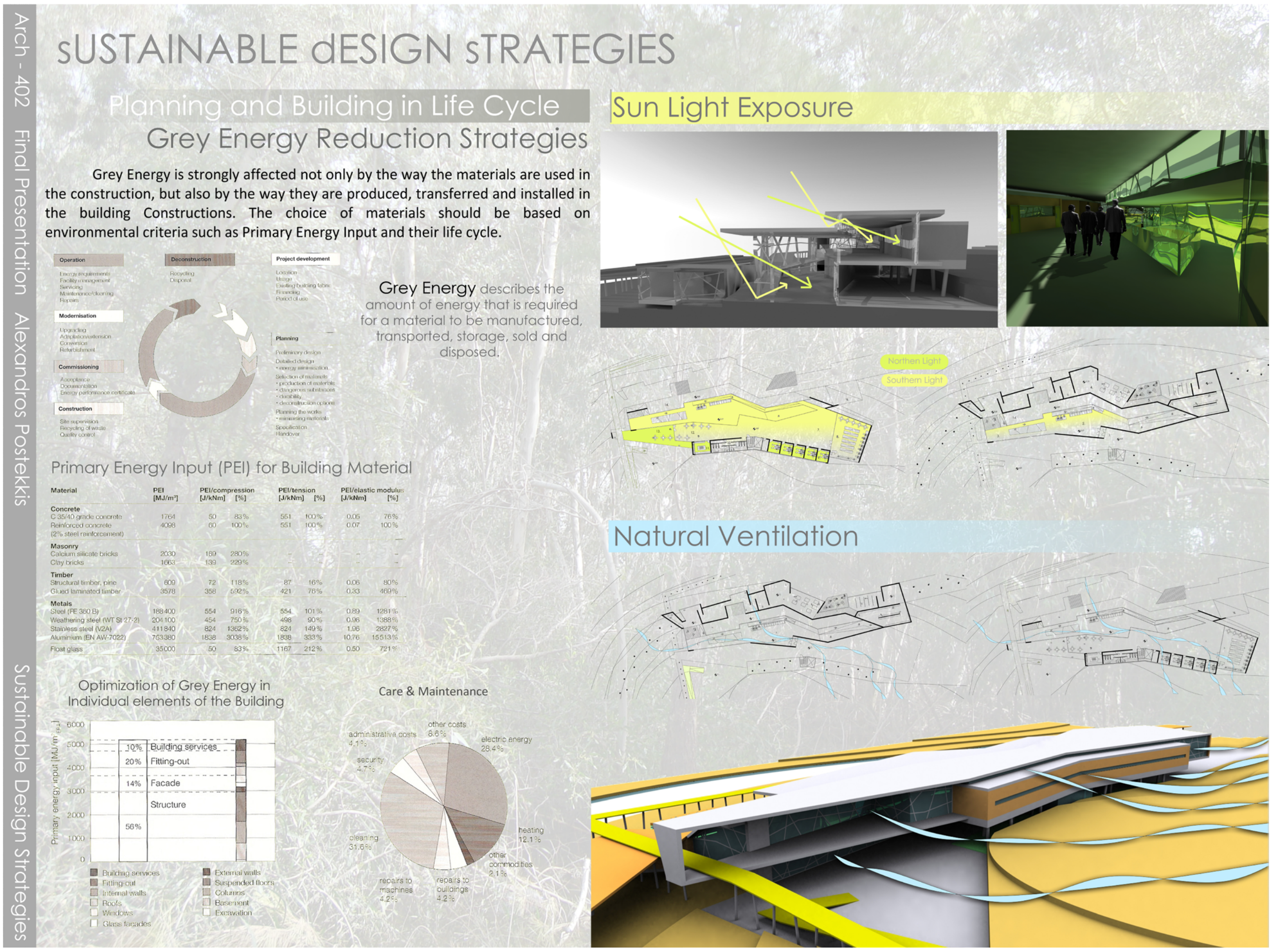


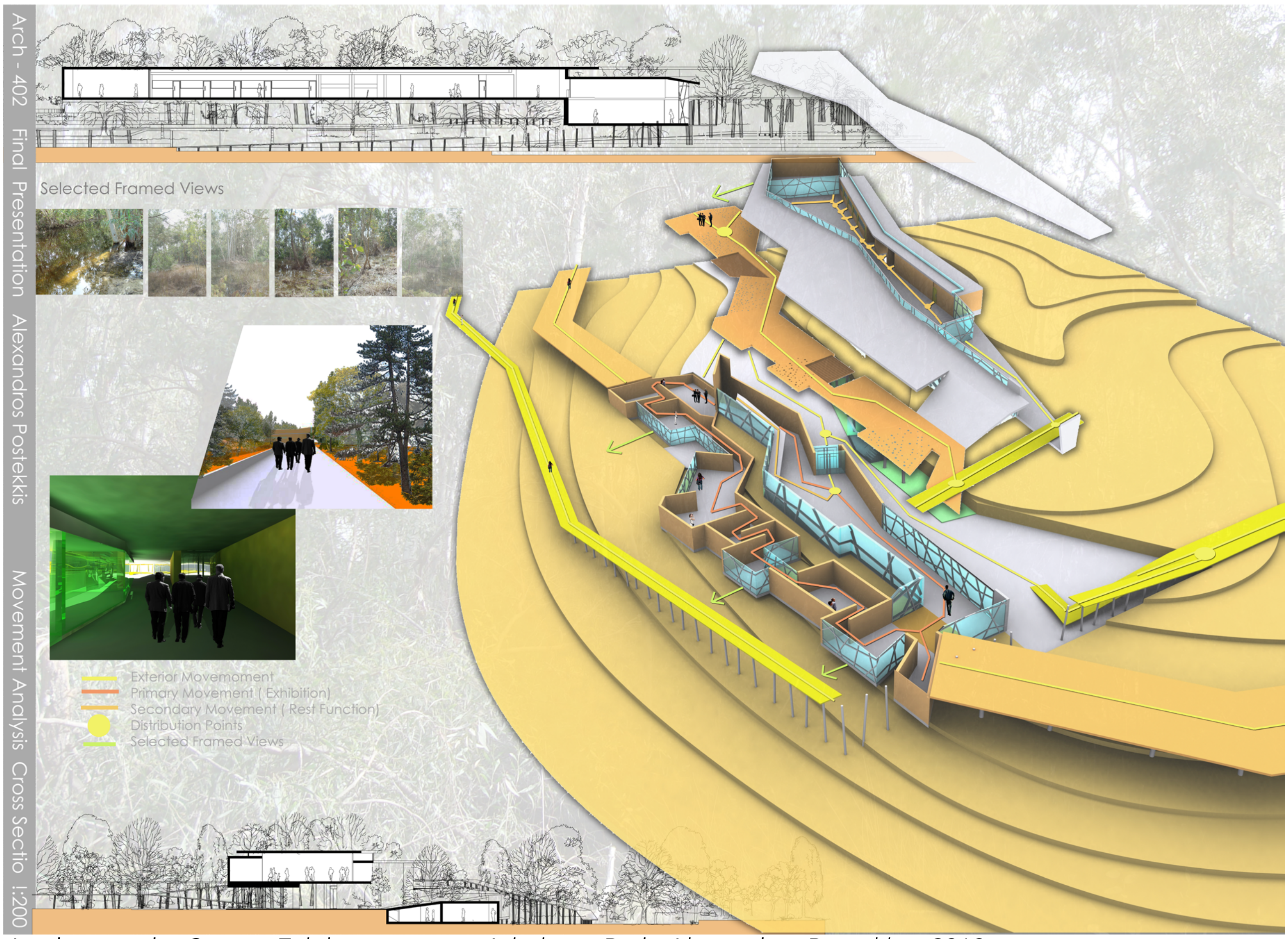
Natural Light in Learning Environments. Lakatamia High School. Katerina Michaelidou. 2011



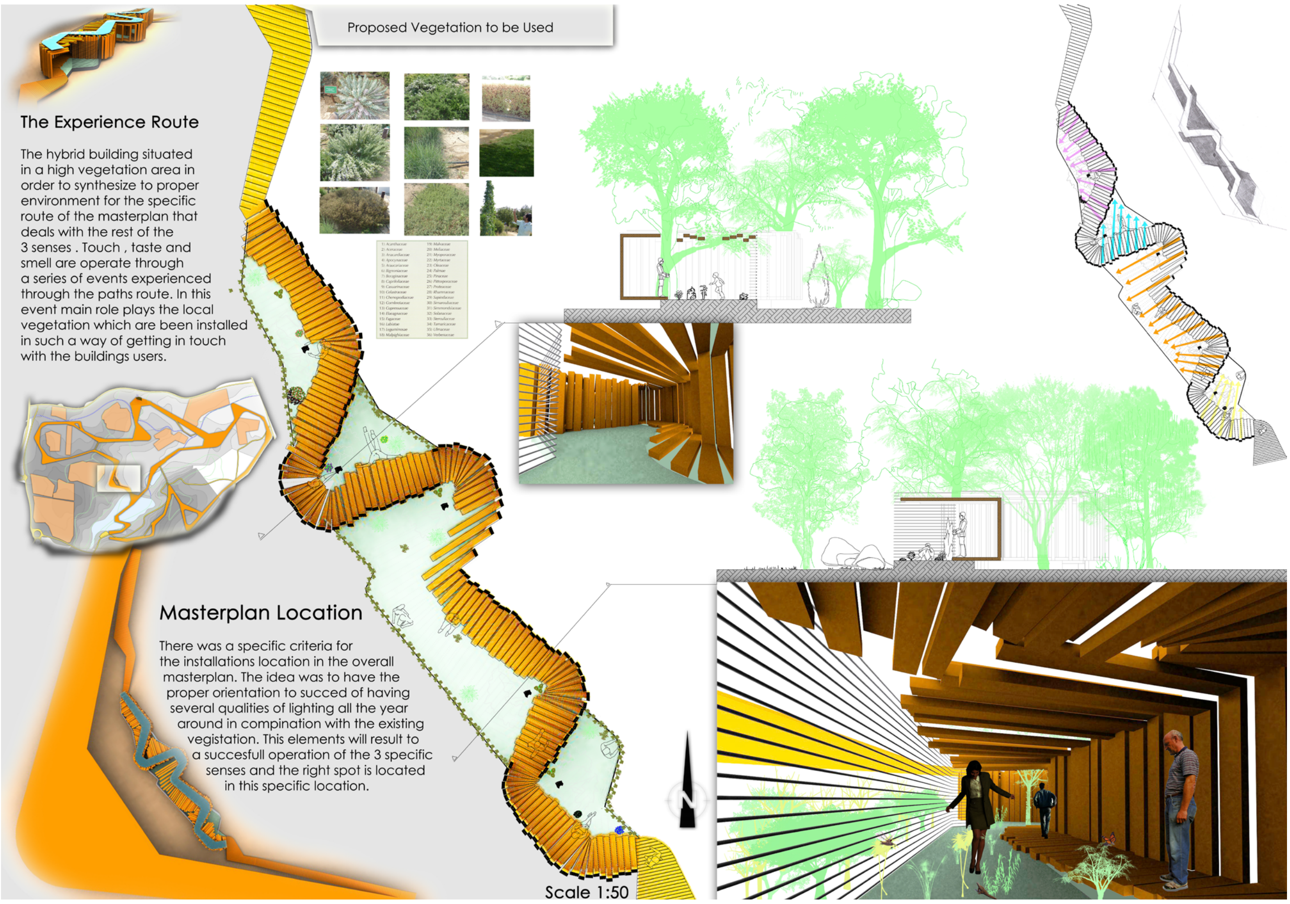


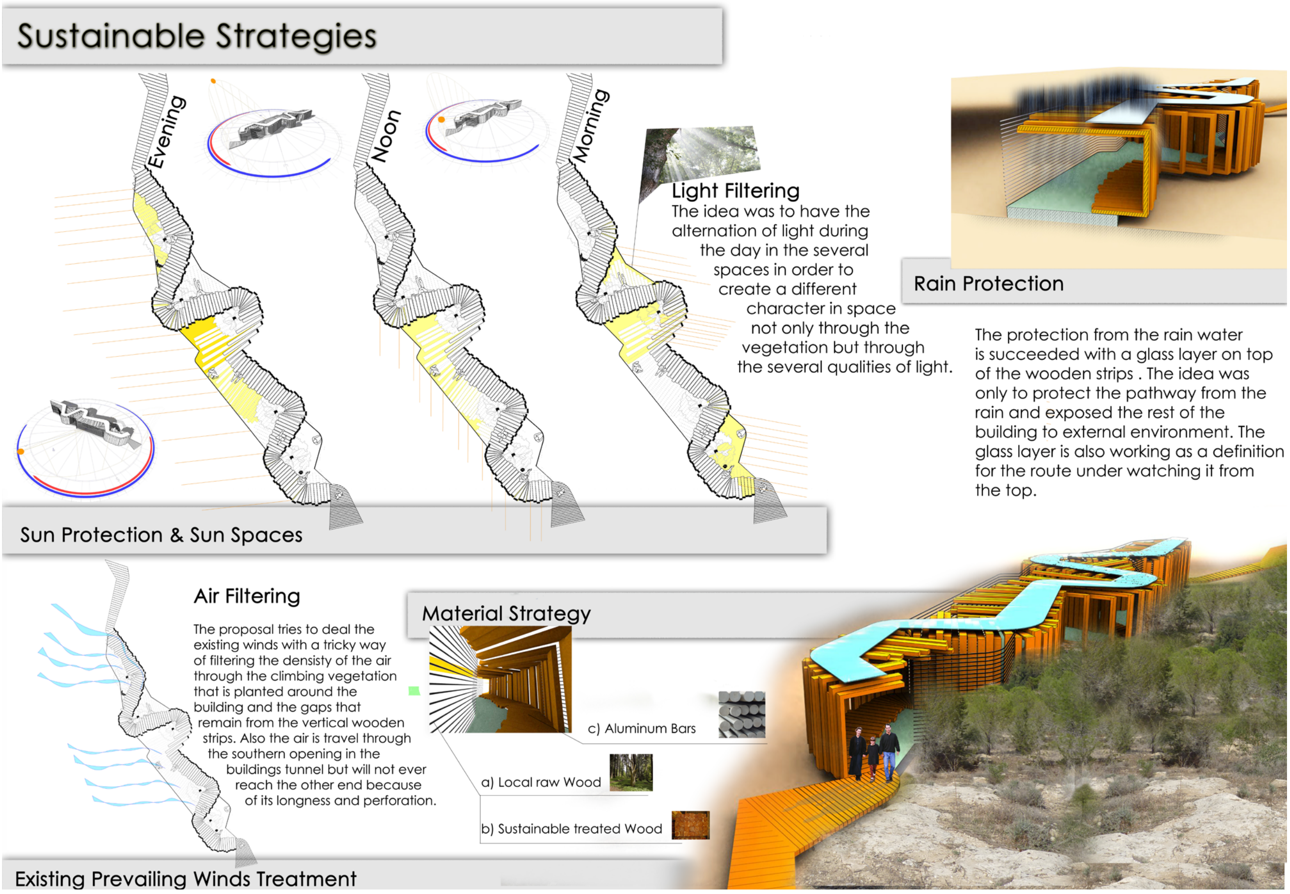
Urban Market Ecology. Nicosia. Anna Margaritova. 2012



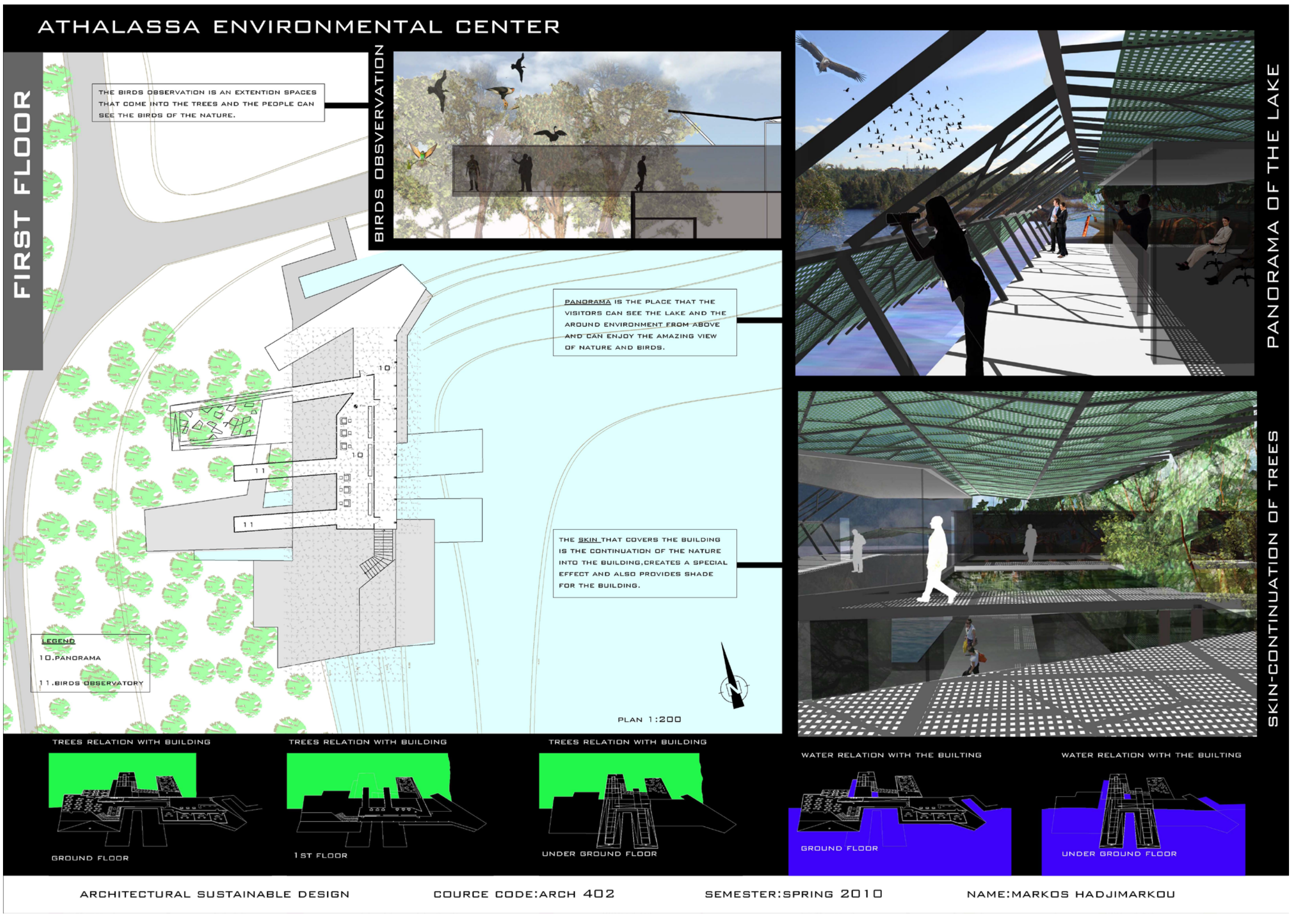


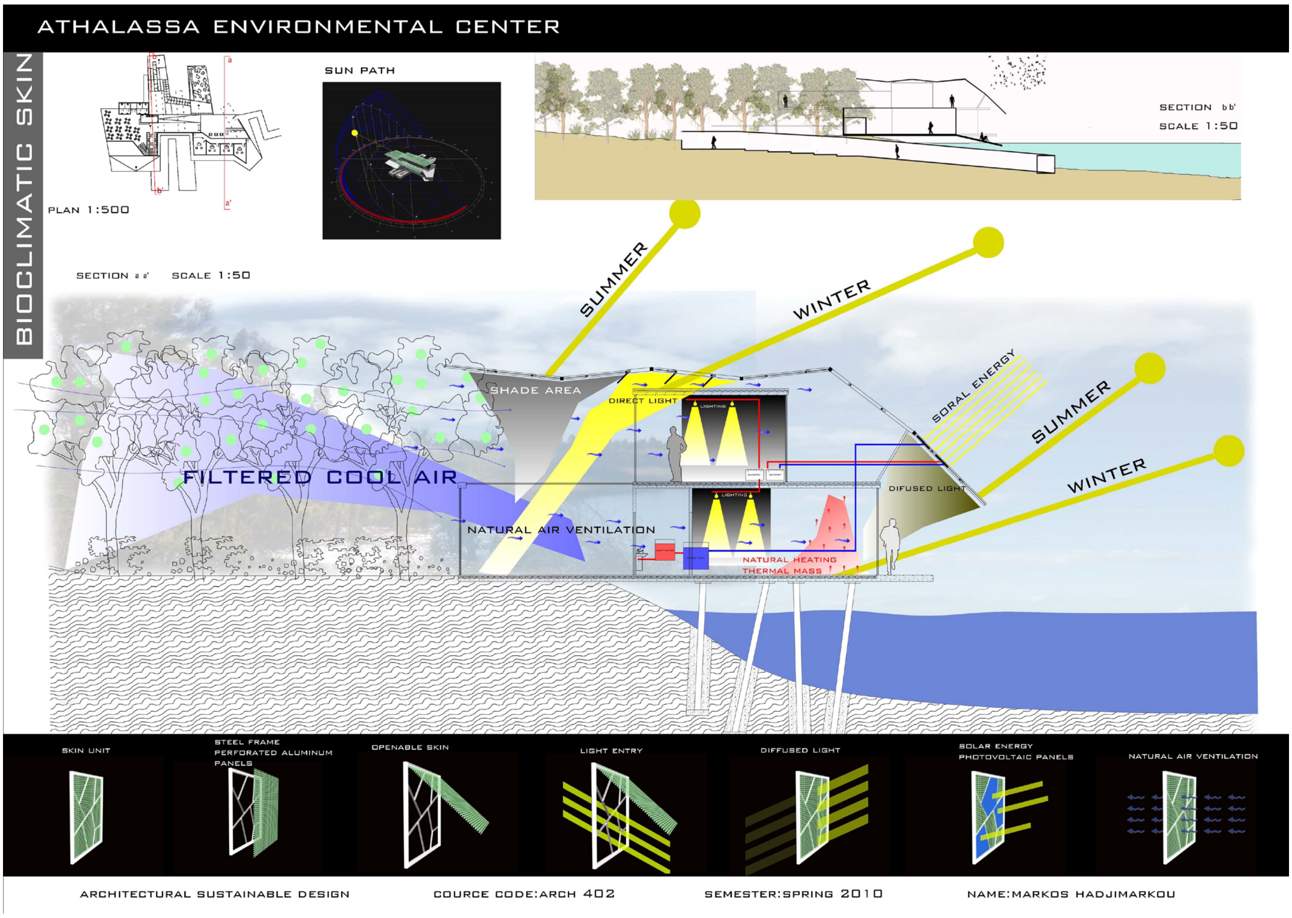
Awakening the Senses Exhibition space. Athalassa Park. Alexandros Postekkis. 2010





Awakening the Senses Pavilion. Athalassa Park. Alexandros Postekkis. 2010





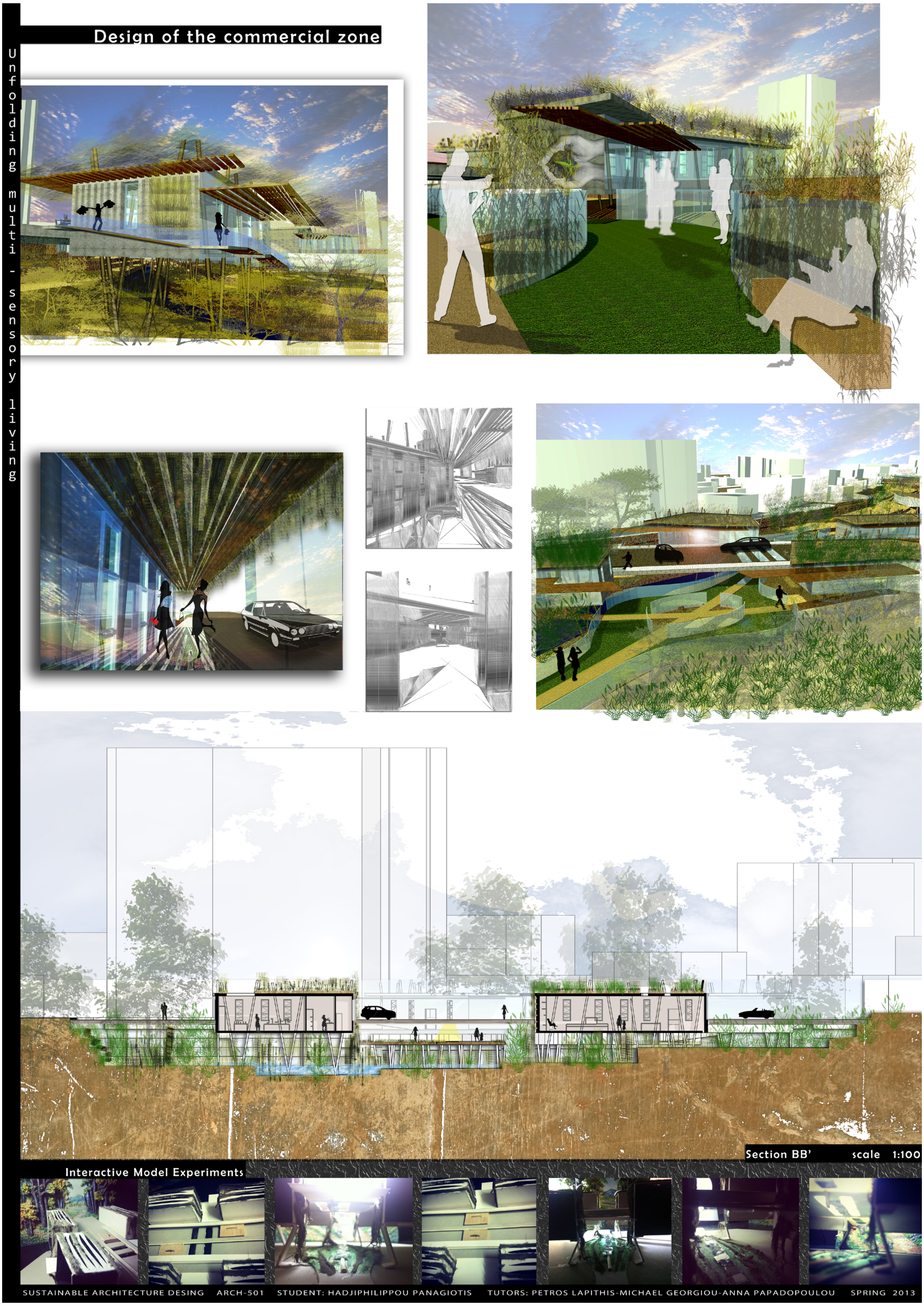
Nature Exploration Park, Athalassa Park. Markos Hadjimarkou. 2010

N

BIODIVERSITY CENTRE PLAN
1:100

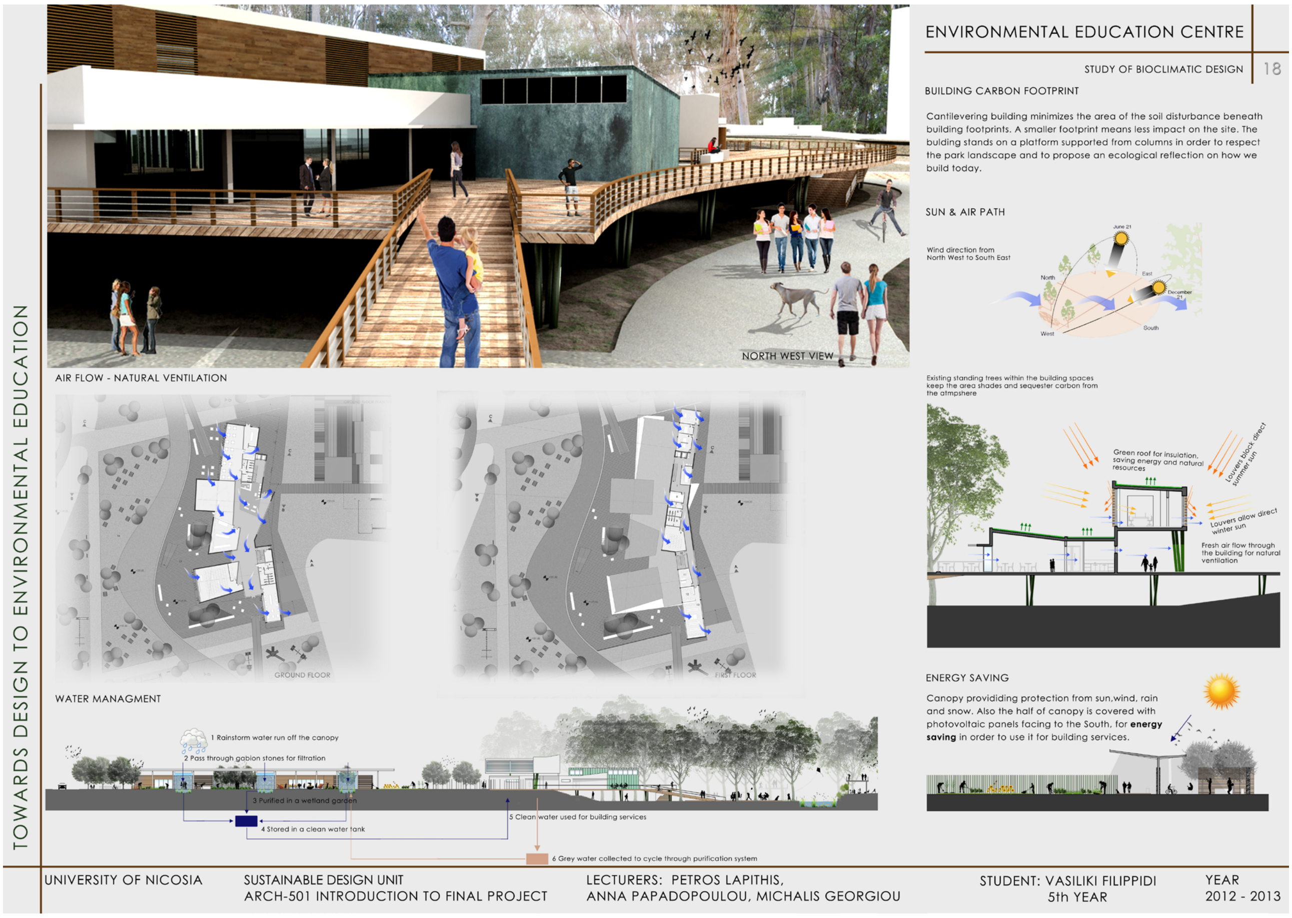
1. Exhibition room 01
2. Exhibition room 02
3. Inner garden/ live exhibition
4. Inner garden
5. Biodiversity craft workshops
6. Inner courtyard
7. Seminar rooms
8. Auditorium/ Multipurpose room
9. Storage
10. Archives
11. Inner garden12. Entry/ ticketing
13. Administration offices
14. Garden

Towards Symbiotic Architecture. Aliki Salt lake. Monika Kakou. 2016

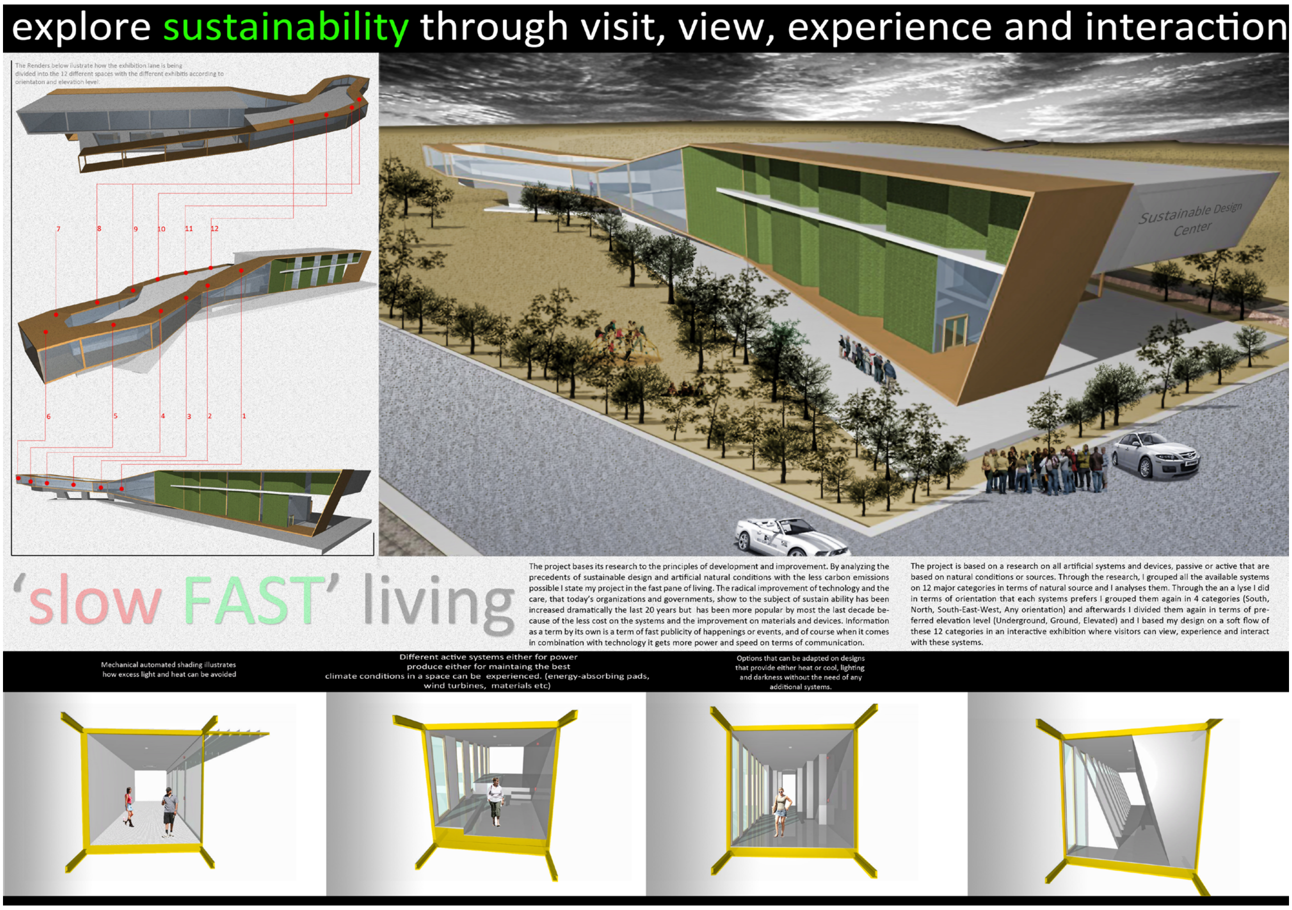


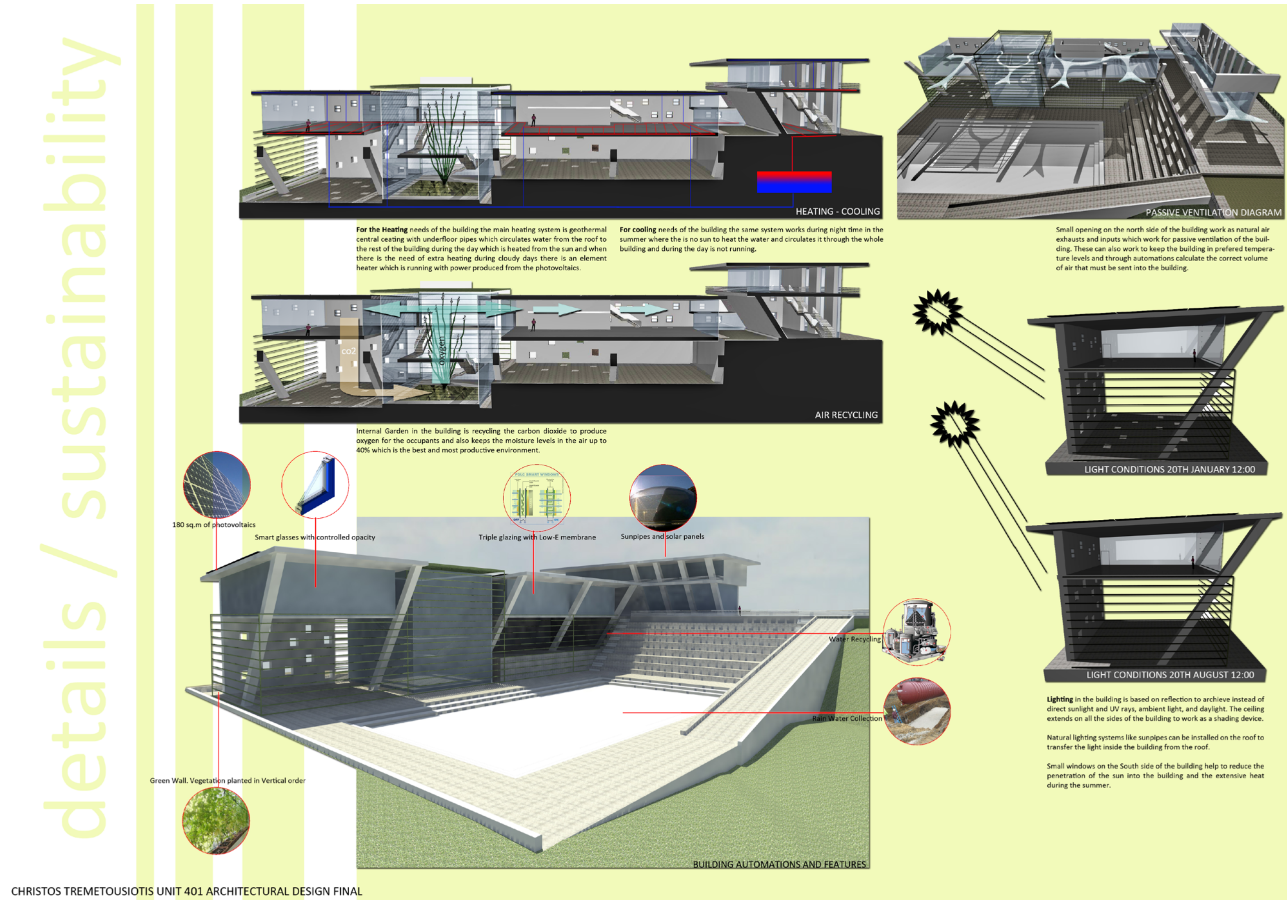
Back to Nature. Pedieos River. Panayiotis Hadjiphillipou. 2013

matic Architect

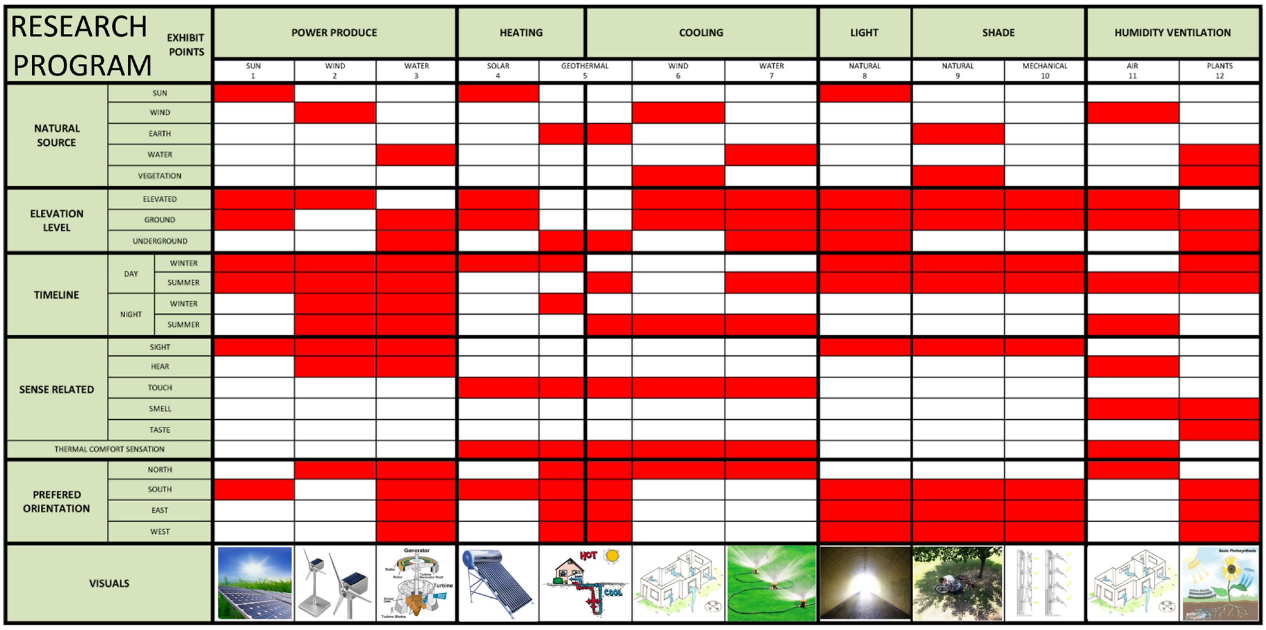


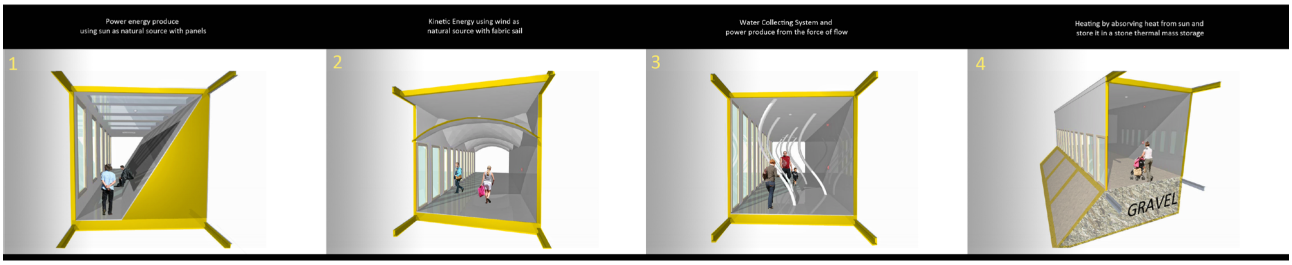
Towards Design to Environmental Education. Pedieos river. Vasiliki Fillippidi. 2013

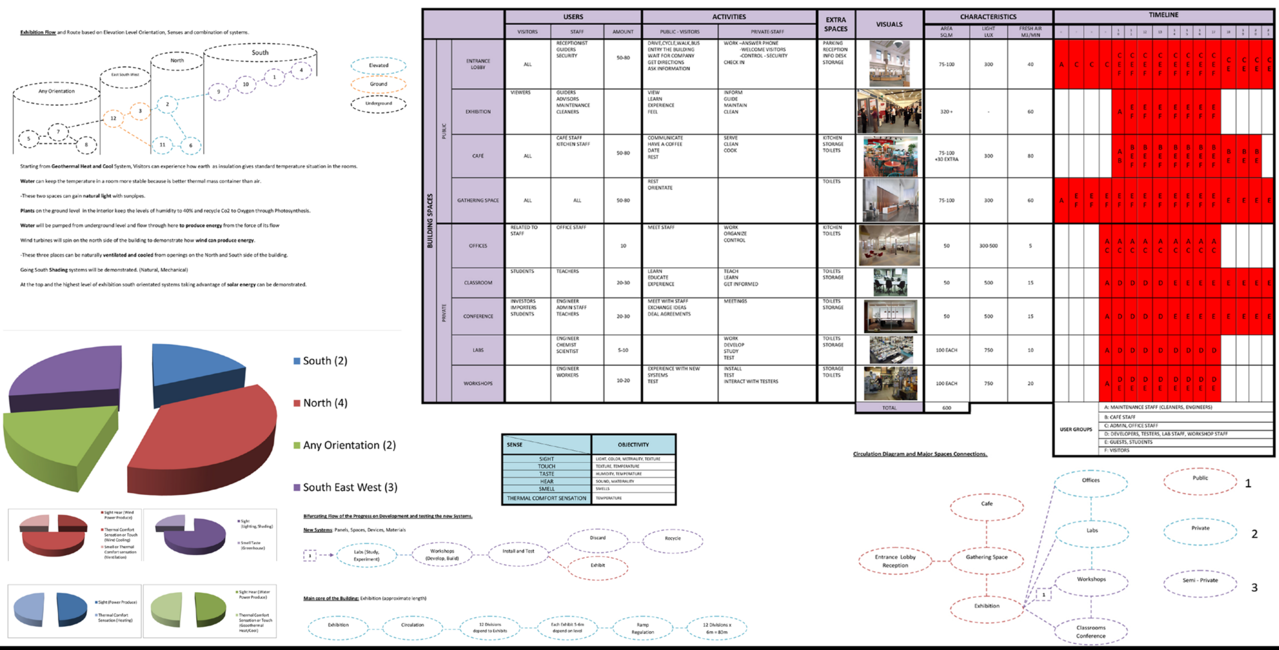


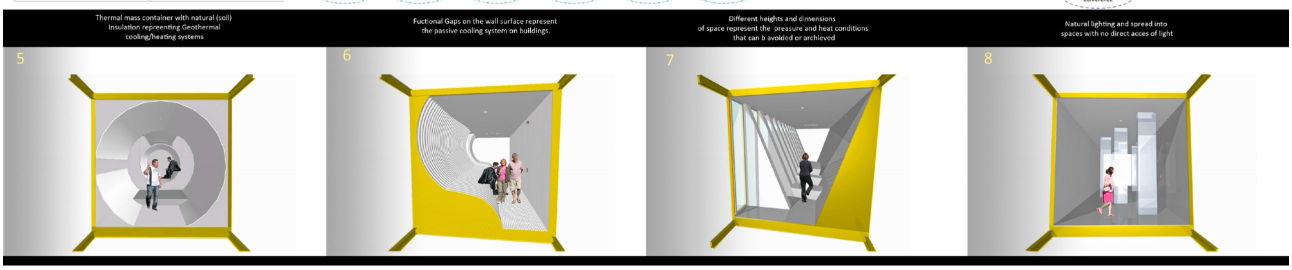


Technology in Architecture. Christos Tremetousiotis. 2011







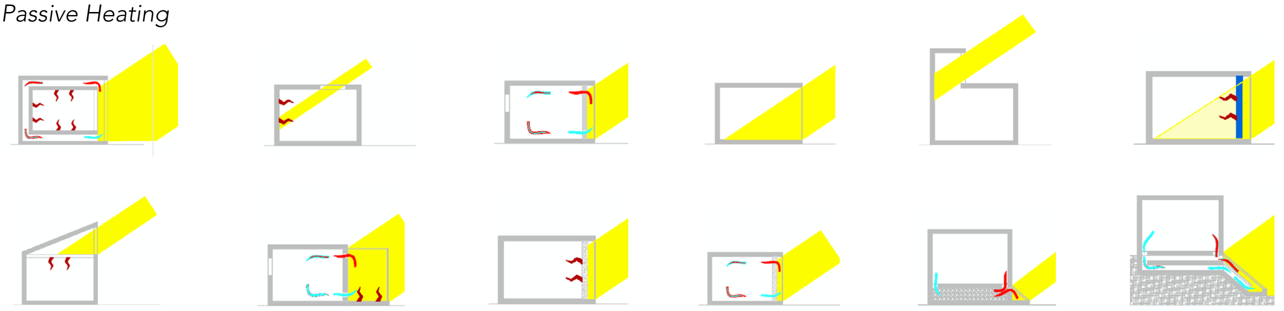


Technology in Architecture. Christos Tremetousiotis. 2011

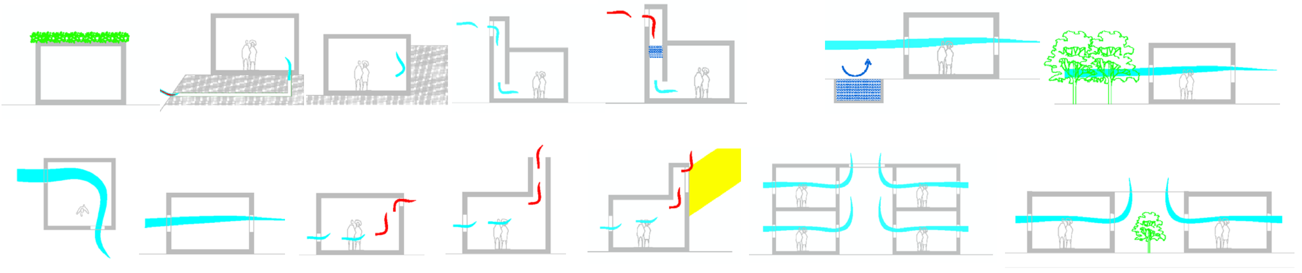
Bioclimatic Strategies: Images

Building Envelope

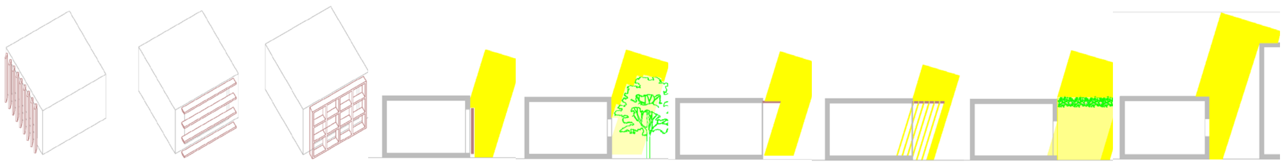
Passive Heating

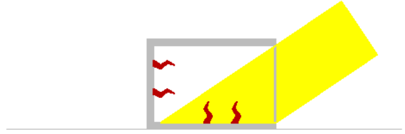


Passive Cooling



Solar Control



BIOCLIMATIC STRATEGIES ΒΙΟΚΛΙΜΑΤΙΚΕΣ ΣΤΡΑΤΗΓΙΚΕΣ	
SOLAR GAIN ΗΛΙΑΚΟ ΚΕΡΔΟΣ	
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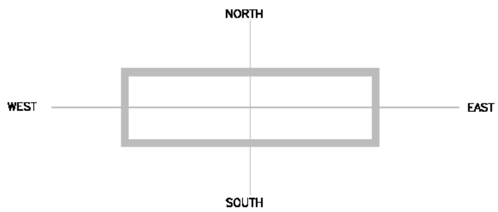
THERMAL INSULATION OF BUILDING ENVELOPE ΘΕΡΜΟΜΟΝΩΣΗ ΚΕΛΥΦΟΥΣ	
BUILDING SHAPE ΣΧΗΜΑ ΚΤΙΡΙΟΥ	
BUILDING ORIENTATION ΠΡΟΣΑΝΑΤΟΛΙΣΜΟΣ ΚΤΙΡΙΟΥ	
SHADING DEVICES ΣΚΙΑΣΤΡΑ	
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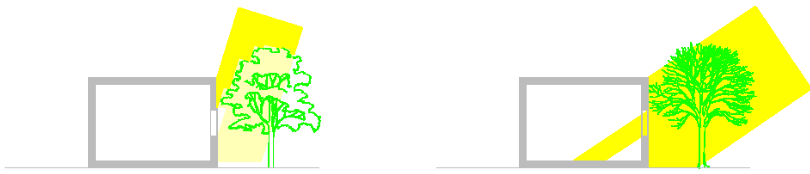
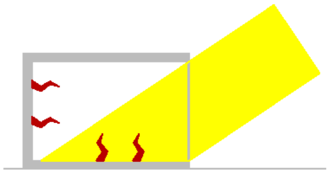
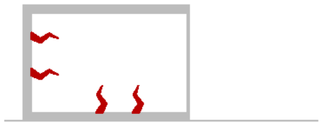
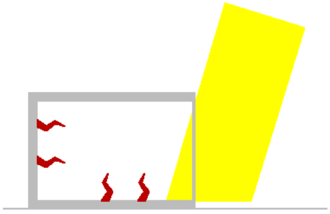
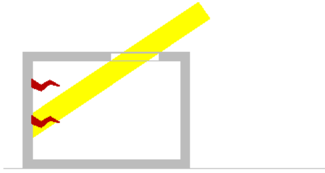
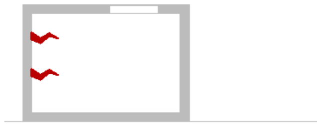
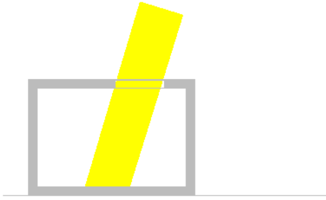
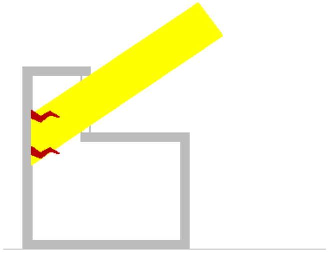
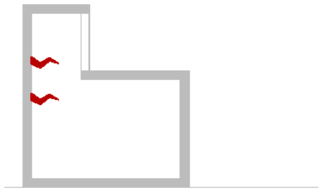
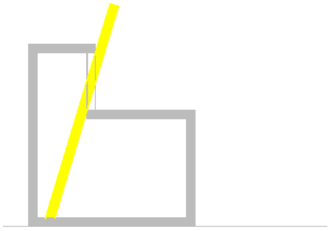
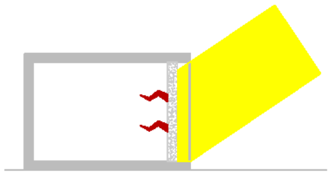
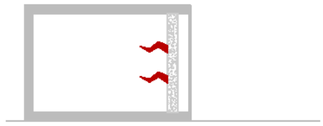
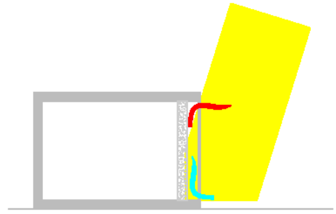
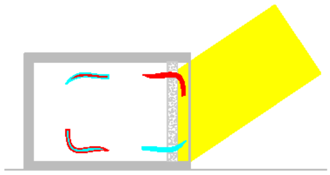
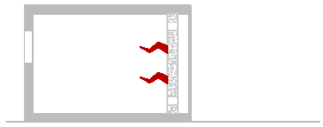
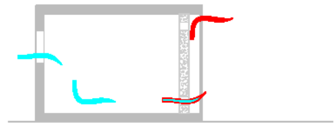
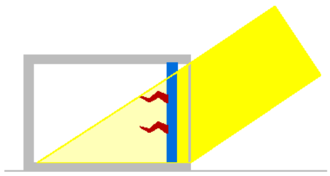
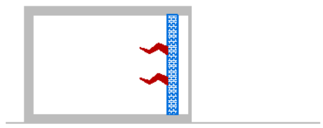
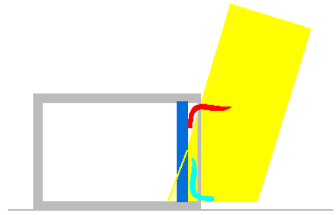
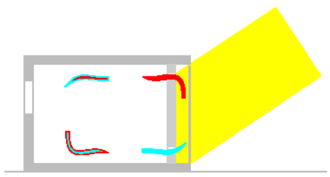
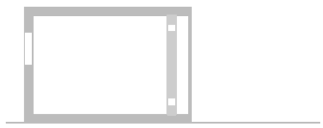
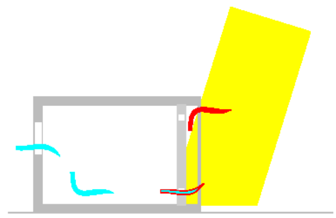
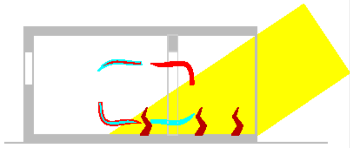
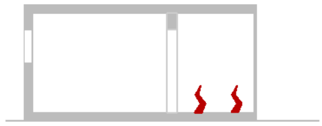
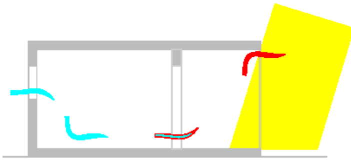
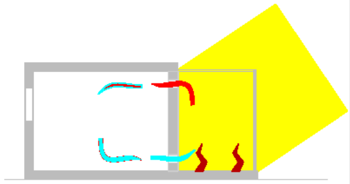
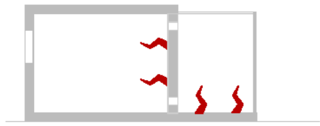
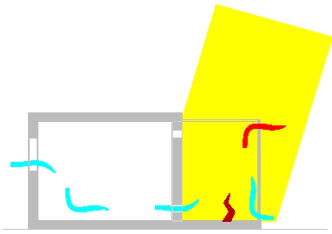
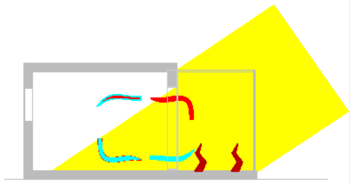
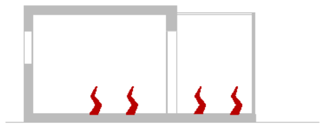
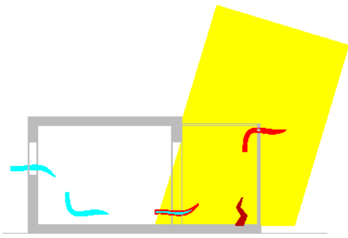
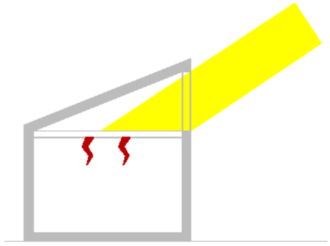
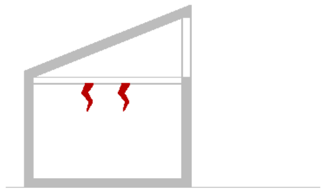
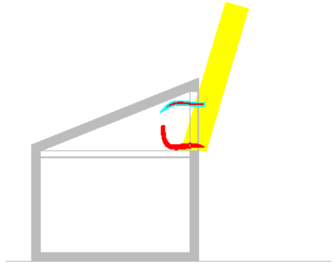
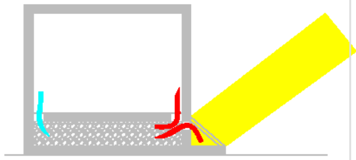
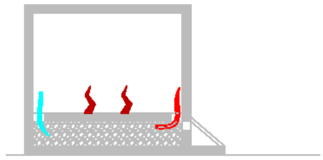
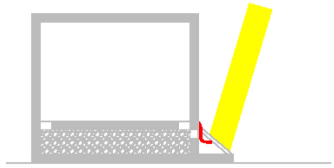
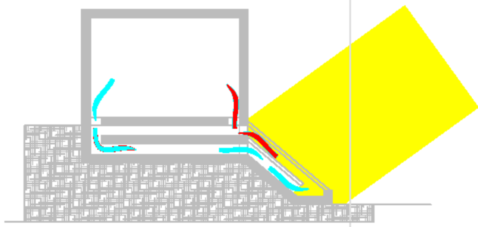
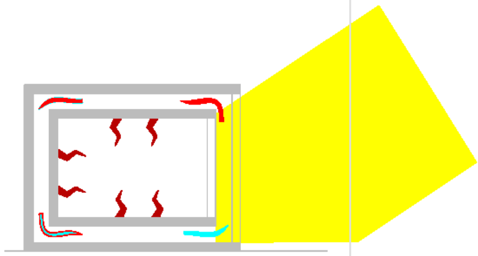
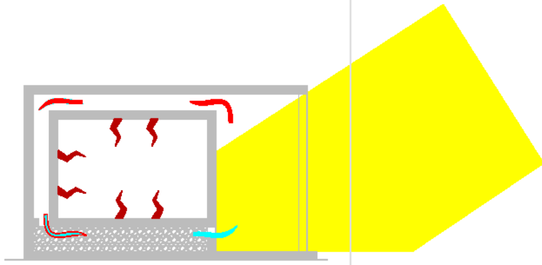
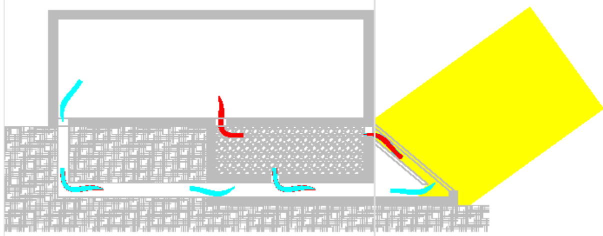
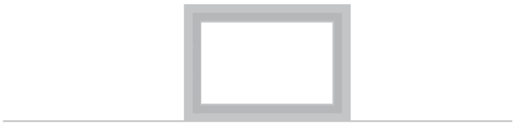
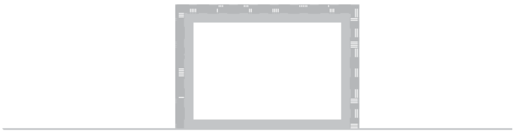
VEGETATION ΦΥΤΕΥΣΗ	

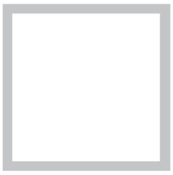
PASSIVE SOLAR HEATING SYSTEMS: DIRECT GAIN ΠΑΘΗΤΙΚΑ ΣΥΣΤΗΜΑΤΑ ΘΕΡΜΑΝΣΗΣ: ΑΜΕΣΣΟ ΚΕΡΔΟΣ	WINTER DAY ΧΕΙΜΩΝΑΣ ΜΕΡΑ	WINTER NIGHT ΧΕΙΜΩΝΑΣ ΝΥΧΤΑ	SUMMER ΚΑΛΟΚΑΙΡΙ
WALL OPENINGS **ΑΝΟΙΓΜΑΤΑ ΣΤΟΝ ΤΟΙΧΟ**			
ROOF OPENINGS **ΑΝΟΙΓΜΑ ΣΤΕΓΗΣ**			
CLERESTORY WINDOWS **ΦΕΓΓΙΤΗΣ**			

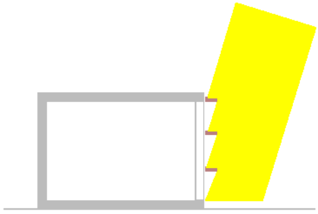
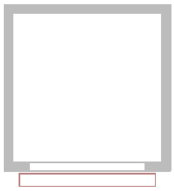
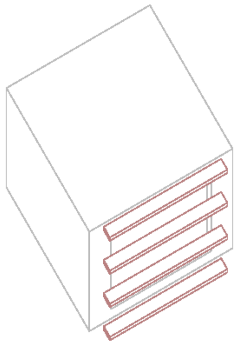
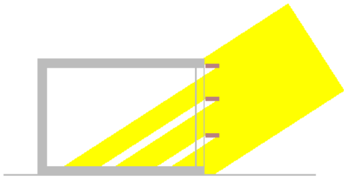
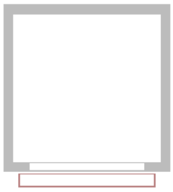
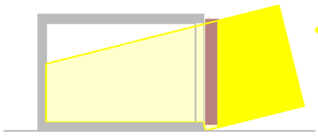
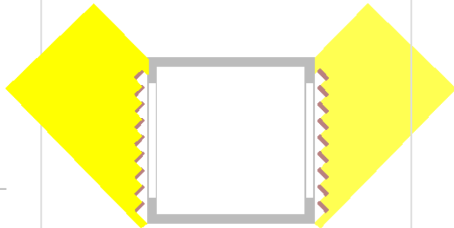
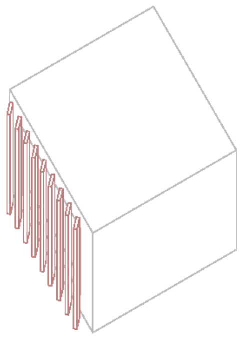
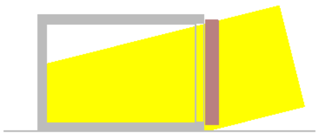
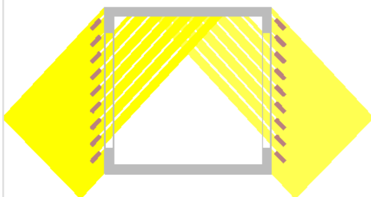
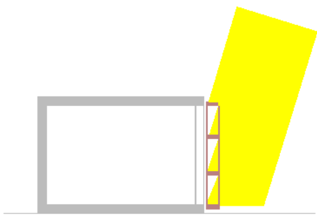
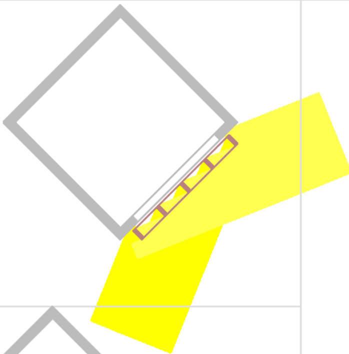
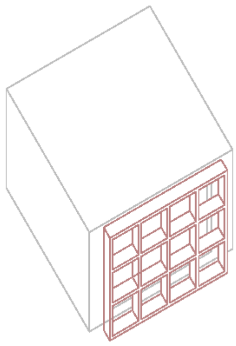
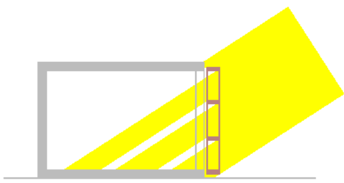
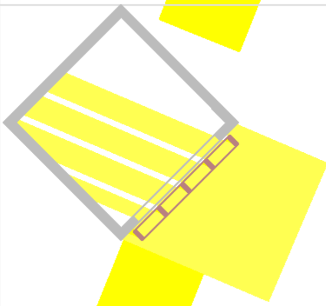
PASSIVE SOLAR HEATING SYSTEMS: INDIRECT GAIN ΠΑΘΗΤΙΚΑ ΣΥΣΤΗΜΑΤΑ ΘΕΡΜΑΝΣΗΣ: ΕΜΕΣΣΟ ΚΕΡΔΟΣ	WINTER DAY ΧΕΙΜΩΝΑΣ ΜΕΡΑ	WINTER NIGHT ΧΕΙΜΩΝΑΣ ΝΥΧΤΑ	SUMMER ΚΑΛΟΚΑΙΡΙ
THERMAL STORAGE WALL (WITHOUT OPENINGS) **ΤΟΙΧΟΣ ΜΑΖΑΣ (ΧΩΡΙΣ ΑΝΟΙΓΜΑΤΑ)**			
THERMAL STORAGE WALL –TROMBE WALL (WITH OPENINGS) **ΤΟΙΧΟΣ ΜΑΖΑΣ -ΤΟΙΧΟΣ TROMBE (ΜΕ ΑΝΟΙΓΜΑΤΑ)**			
THERMAL STORAGE WATER WALL **ΤΟΙΧΟΣ ΝΕΡΟΥ**			
SOLAR AIR COLLECTOR **ΣΥΛΛΕΚΤΗΣ ΗΛΙΑΚΟΥ ΑΕΡΑ**			

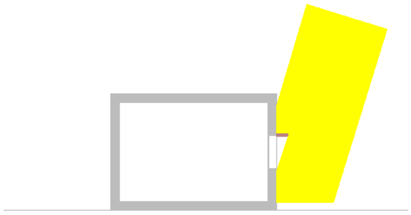
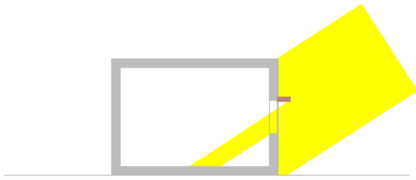
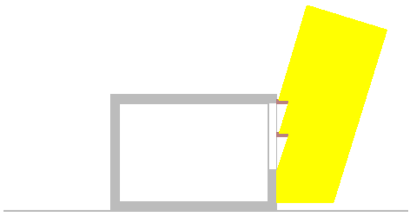
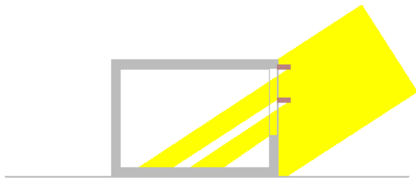
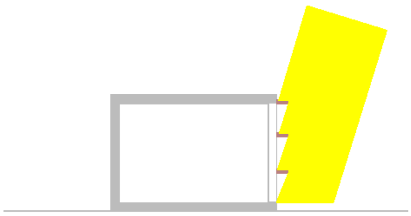
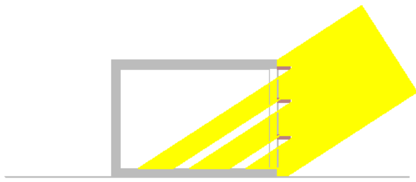
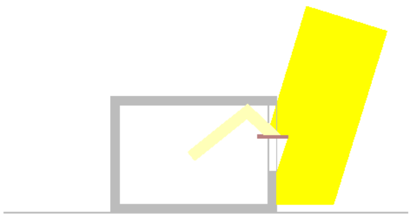
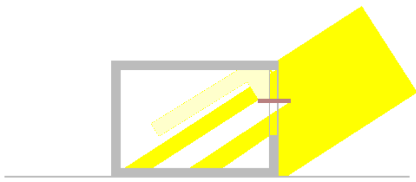
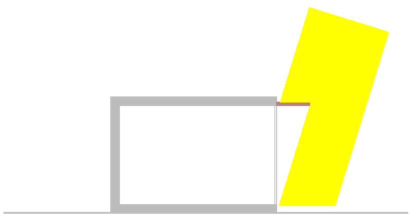
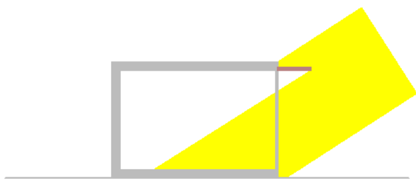
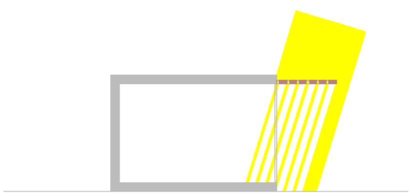
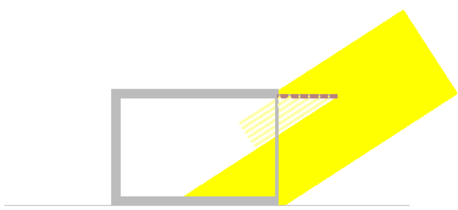
PASSIVE SOLAR HEATING: ISOLATED GAIN ΠΑΘΗΤΙΚΑ ΣΥΣΤΗΜΑΤΑ ΘΕΡΜΑΝΣΗΣ: ΑΠΟΜΟΝΩΜΕΝΟ ΚΕΡΔΟΣ	WINTER DAY ΧΕΙΜΩΝΑΣ ΜΕΡΑ	WINTER NIGHT ΧΕΙΜΩΝΑΣ ΝΥΧΤΑ	SUMMER ΚΑΛΟΚΑΙΡΙ
SUNSPACES (DOOR OPENING) **ΘΕΡΜΟΚΗΠΙΟ (ΑΝΟΙΓΜΑ ΠΟΡΤΑΣ)**			
SUNSPACE (OPENINGS) **ΘΕΡΜΟΚΗΠΙΟ (ΑΝΟΙΓΜΑΤΑ)**			
SUNSPACES (DOOR) **ΘΕΡΜΟΚΗΠΙΟ (ΑΝΟΙΓΜΑΤΑ)**			

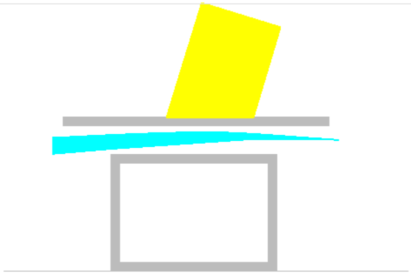
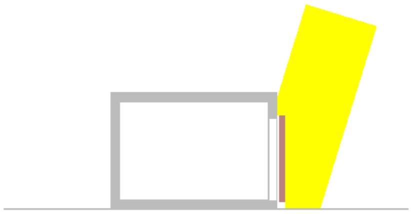
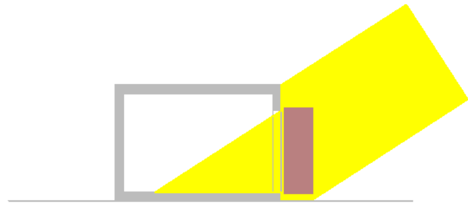
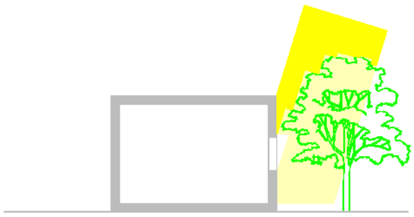
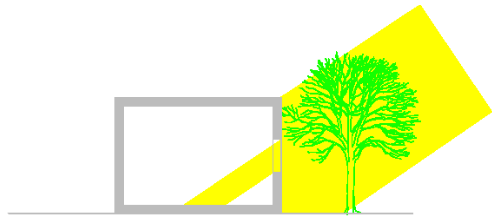
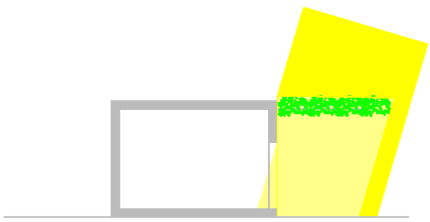
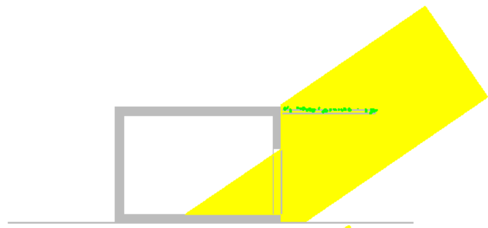
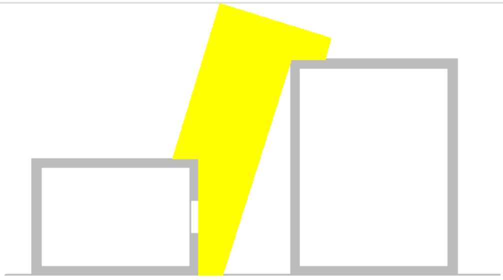
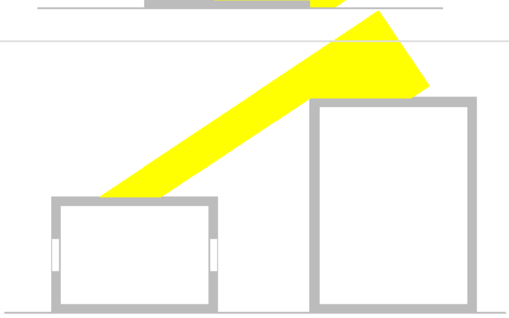
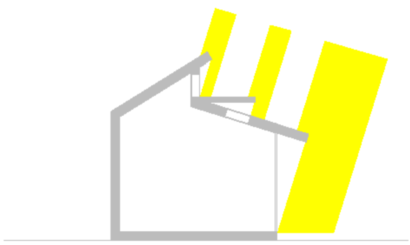
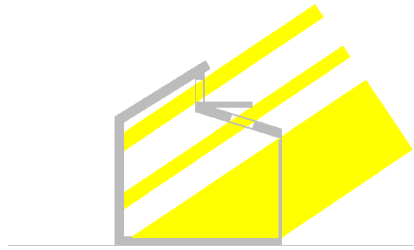
PASSIVE SOLAR HEATING SYSTEMS ΠΑΘΗΤΙΚΑ ΣΥΣΤΗΜΑΤΑ ΘΕΡΜΑΝΣΗΣ	WINTER DAY ΧΕΙΜΩΝΑΣ ΜΕΡΑ	WINTER NIGHT ΧΕΙΜΩΝΑΣ ΝΥΧΤΑ	SUMMER ΚΑΛΟΚΑΙΡΙ
SOLAR ROOF **ΗΛΙΑΚΗ ΣΤΕΓΗ**			
THERMOSIPHON SYSTEM WITH ROCK BED **ΣΥΣΤΗΜΑ ΘΕΡΜΟΣΙΦΩΝΑ**			
THERMOSIPHON SYSTEM **ΣΥΣΤΗΜΑ ΘΕΡΜΟΣΙΦΩΝΑ**			
DOUBLE ENVELOPE —BARRA CONSTANTINI **ΔΙΠΛΟ ΚΕΛΥΦΟΣ**—BARRA CONSTANTINI			
DOUBLE ENVELOPE AND THERMOSIPHON SYSTEM **ΔΙΠΛΟ ΚΕΛΥΦΟΣ ΚΑΙ ΣΥΣΤΗΜΑ ΘΕΡΜΟΣΙΦΩΝΙΣΜΟΥ**			
THERMOSIPHON SYSTEM **ΣΥΣΤΗΜΑ ΘΕΡΜΟΣΙΦΩΝΙΣΜΟΥ**			

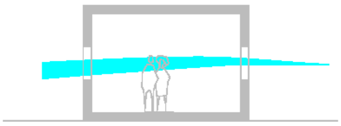
BUILDING ENVELOPE ΚΕΛΥΦΟΣ ΚΤΙΡΙΟΥ	
THERMAL MASS ΘΕΡΜΙΚΗ ΜΑΖΑ	
THERMAL INSULATION OF BUILDING ENVELOPE –EXTERNAL ΘΕΡΜΟΜΟΝΩΣΗ ΚΕΛΥΦΟΥΣ-ΕΞΩΤΕΡΙΚΗ	
THERMAL INSULATION OF BUILDING ENVELOPE–INTERNAL ΘΕΡΜΟΜΟΝΩΣΗ ΚΕΛΥΦΟΥΣ -ΕΣΩΤΕΡΙΚΗ	

BUILDING SHAPE ΣΧΗΜΑ ΚΤΙΡΙΟΥ	
SQUARE ΤΕΤΡΑΓΩΝΟ	
RECTANGLE ΟΡΘΟΓΩΝΙΟ	
Π - SHAPE ΣΧΗΜΑ Π	

SHADING DEVICES ΗΛΙΟΠΡΟΣΤΑΣΙΑ- ΣΚΙΑΣΤΡΑ	SECTION ΤΟΜΗ	PLAN ΚΑΤΟΨΗ	AXONOMETRIC ΑΞΟΝΟΜΕΤΡΙΚΟ
HORIZONTAL –SOUTH **SIDE** SUMMER –MIDDAY ΟΡΙΖΟΝΤΙΑ - ΝΟΤΙΑ ΠΛΕΥΡΑ ΚΑΛΟΚΑΙΡΙ -ΜΕΣΗΜΕΡΙ			
HORIZONTAL –SOUTH **SIDE** **WINTER -MIDDAY** ΟΡΙΖΟΝΤΙΑ - ΝΟΤΙΑ ΠΛΕΥΡΑ ΧΕΙΜΩΝΑΣ - ΜΕΣΗΜΕΡΙ			
VERTICAL –EAST & WEST SIDE SUMMER –MORNING & AFTERNOON ΚΑΘΕΤΑ - ΑΝΑΤΟΛΙΚΗ & ΔΥΤΙΚΗ ΠΛΕΥΡΑ ΚΑΛΟΚΑΙΡΙ - ΠΡΩΙ & ΑΠΟΓΕΥΜΑ			
VERTICAL –EAST & WEST SIDE WINTER –MORNING & AFTERNOON ΚΑΘΕΤΑ - ΑΝΑΤΟΛΙΚΗ & ΔΥΤΙΚΗ ΠΛΕΥΡΑ ΧΕΙΜΩΝΑΣ -ΠΡΩΙ & ΑΠΟΓΕΥΜΑ			
EGG CRATE –SOUTHEAST & SOUTHWEST SIDE SUMMER –MORNING, MIDAY, AFTERNOON ΣΧΑΡΑ -ΝΟΤΙΟΑΝΑΤΟΛΙΚΗ & ΝΟΤΙΟΔΥΤΙΚΗ ΠΛΕΥΡΑ ΚΑΛΟΚΑΙΡΙ -ΠΡΩΙ, ΜΕΣΗΜΕΡΙ, ΑΠΟΓΕΥΜΑ			
EGG CRATE –SOUTHEAST & SOUTHWEST SIDE WINTER – MORNING, MIDAY, AFTERNOON ΣΧΑΡΑ -ΝΟΤΙΟΑΝΑΤΟΛΙΚΗ & ΝΟΤΙΟΔΥΤΙΚΗ ΠΛΕΥΡΑ ΧΕΙΜΩΝΑΣ -ΠΡΩΙ, ΜΕΣΗΜΕΡΙ, ΑΠΟΓΕΥΜΑ			

SHADING METHODS ΜΕΘΟΔΟΙ ΣΚΙΑΣΗΣ	SUMMER ΚΑΛΟΚΑΙΡΗ	WINTER ΧΕΙΜΩΝΑΣ
HORIZONTAL SHADING DEVICES ΟΡΙΖΟΝΤΙΑ ΣΚΙΑΣΤΡΑ		
HORIZONTAL SHADING DEVICES ΟΡΙΖΟΝΤΙΑ ΣΚΙΑΣΤΡΑ		
HORIZONTAL SHADING DEVICES ΟΡΙΖΟΝΤΙΑ ΣΚΙΑΣΤΡΑ		
HORIZONTAL SHADING DEVICES LIGHT SHELVE ΟΡΙΖΟΝΤΙΑ ΣΚΙΑΣΤΡΑ		
OVERHANG ΕΞΟΧΗ		
PERGOLA ΠΕΡΓΟΛΑ		

SHADING METHODS ΜΕΘΟΔΟΙ ΣΚΙΑΣΗΣ	SUMMER ΚΑΛΟΚΑΙΡΗ	WINTER ΧΕΙΜΩΝΑΣ
SHADED ROOF ΣΚΙΑΣΜΕΝΗ ΟΡΟΦΗ		
CONTROLED EXTERNAL SHADING DEVICE ΡΥΘΜΙΖΟΜΕΝΗ ΣΚΙΑΣΗ ΜΕΣΩ ΕΞΩΤΕΡΙΚΩΝ ΠΕΤΑΣΜΑΤΩΝ (ΠΑΤΖΟΥΡΙΑ)		
VEGETATION ΦΥΤΕΥΣΗ		
VEGETATION–PERGOLA ΑΝΑΡΡΙΧΗΤΙΚΑ ΦΥΤΑ-ΠΕΡΓΟΛΑ		
SHADING BY NEARBY BUILDINGS ΣΚΙΑΣΜΟΣ ΑΠΟ ΓΕΙΤΟΝΙΚΑ ΚΤΙΡΙΑ		
ROOF OPENINGS, CLERESTORY WINDOWS, WALL OPENINGS ΑΝΟΙΓΜΑ ΣΤΕΓΗΣ, ΦΕΓΓΙΤΗ, ΤΟΙΧΟΥ		

PASSIVE COOLING SYSTEMS ΠΑΘΗΤΙΚΑ ΣΥΣΤΗΜΑΤΑ ΔΡΟΣΙΣΜΟΥ	CROSS VENTILATION ΔΙΑΜΠΕΡΕΣ ΑΕΡΙΣΜΟΣ
CROSS VENTILATION ΔΙΑΜΠΕΡΕΣ ΑΕΡΙΣΜΟΣ	
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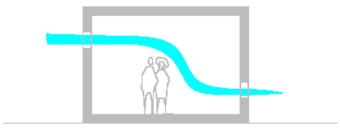
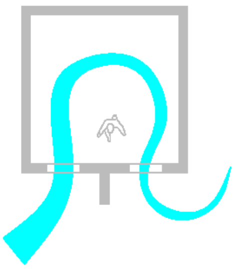
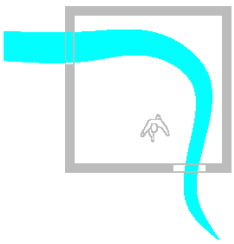
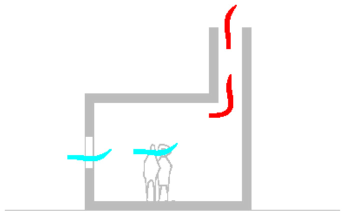
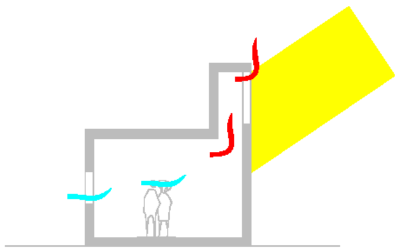
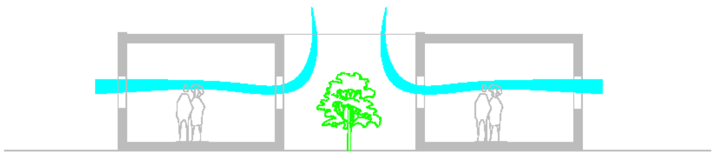
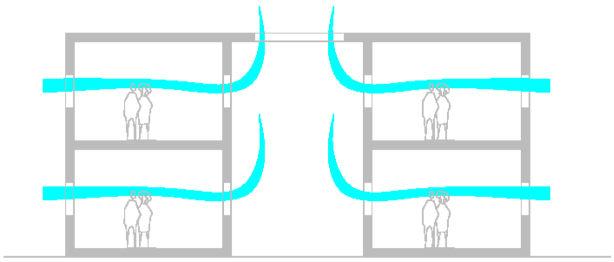
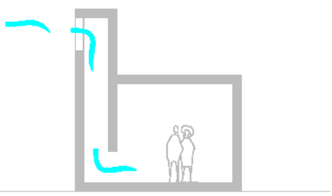
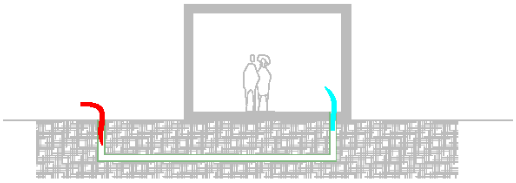
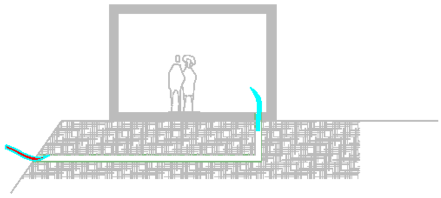
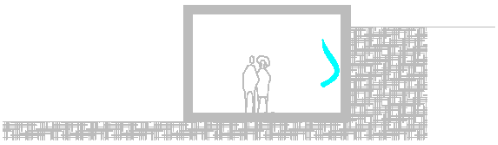
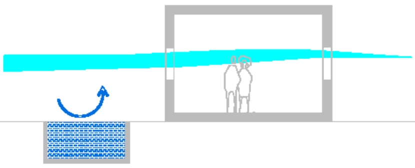
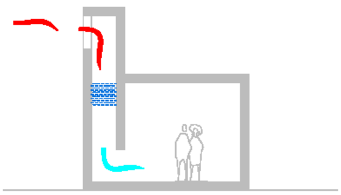
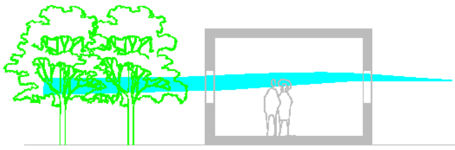
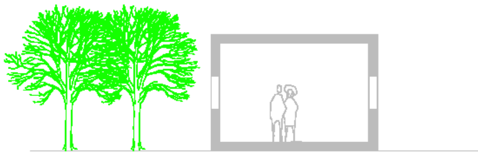
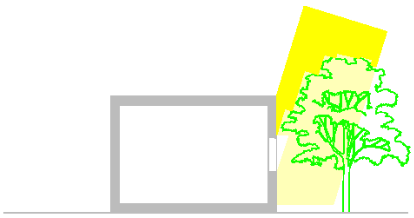
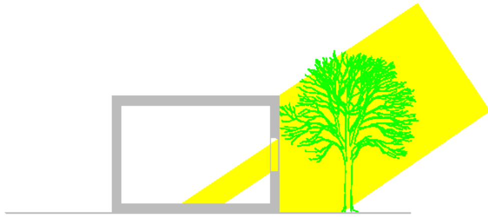
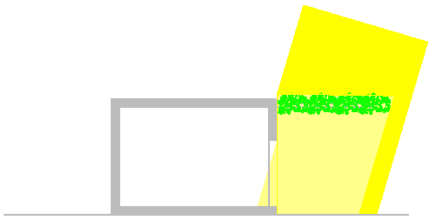
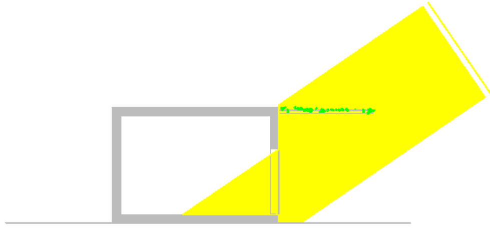
CROSS VENTILATION ΔΙΑΜΠΕΡΕΣ ΑΕΡΙΣΜΟΣ	
CROSS VENTILATION ΔΙΑΜΠΕΡΕΣ ΑΕΡΙΣΜΟΣ	
CROSS VENTILATION ΔΙΑΜΠΕΡΕΣ ΑΕΡΙΣΜΟΣ	

PASSIVE COOLING SYSTEMS ΠΑΘΗΤΙΚΑ ΣΥΣΤΗΜΑΤΑ ΔΡΟΣΙΣΜΟΥ	NATURAL VENTILATION ΦΥΣΙΚΟΣ ΑΕΡΙΣΜΟΣ
STACK EFFECT STACK EFFECT	
CLERESTORY WINDOWS ΑΠΑΓΩΓΗ ΘΕΡΜΟΥ ΑΕΡΑ ΜΕΣΩ ΦΕΓΓΙΤΩΝ	
SOLAR CHIMNEY ΗΛΙΑΚΗ ΚΑΜΙΝΑΔΑ	
COURTYARD ΕΣΩΤΕΡΙΚΗ ΑΥΛΗ	
ATRIUM ΑΙΘΡΙΟ	
WIND CATCHER ΣΥΛΛΕΚΤΗΣ ΑΕΡΟΣ	

PASSIVE COOLING SYSTEMS ΠΑΘΗΤΙΚΑ ΣΥΣΤΗΜΑΤΑ ΔΡΟΣΙΣΜΟΥ	NATURAL VENTILATION ΦΥΣΙΚΟΣ ΑΕΡΙΣΜΟΣ
EARTH COOLING ΔΡΟΣΙΣΜΟΣ ΜΕΣΩ ΥΠΕΔΑΦΙΟΥ ΣΥΣΤΗΜΑΤΟΣ ΑΓΩΓΩΝ	
EARTH COOLING ΔΡΟΣΙΣΜΟΣ ΜΕΣΩ ΥΠΕΔΑΦΙΟΥ ΣΥΣΤΗΜΑΤΟΣ ΑΓΩΓΩΝ	
EARTH COOLING ΔΡΟΣΙΣΜΟΣ ΛΟΓΩ ΗΜΙΥΠΟΣΚΑΦΟΥ ΚΤΙΡΙΟΥ	
EVAPORATIVE COOLING ΕΞΑΤΜΙΣΗ ΝΕΡΟΥ	
WIND CATCHER AND WATER EVAPORATION ΔΡΟΣΙΣΜΟΣ ΜΕ ΕΞΑΤΜΙΣΗ ΑΠΟ ΠΥΡΓΟ ΨΥΞΗΣ	

PASSIVE COOLING SYSTEMS ΠΑΘΗΤΙΚΑ ΣΥΣΤΗΜΑΤΑ ΔΡΟΣΙΣΜΟΥ	SUMMER ΚΑΛΟΚΑΙΡΗ	WINTER ΧΕΙΜΩΝΑΣ
VEGETATION ΦΥΤΕΥΣΗ		
VEGETATION ΦΥΤΕΥΣΗ		
VEGETATION—PERGOLA ΑΝΑΡΡΙΧΗΤΙΚΑ ΦΥΤΑ-ΠΕΡΓΟΛΑ		
GREEN ROOF ΠΡΑΣΙΝΗ ΣΤΕΓΗ		

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Books:

- E-book "Building Blocks for Social Sustainability: Nicosia, Cyprus"
  View low resolution book:
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Videos on bioclimatic architecture:

- Documentary- CyBC & Ministry of Commerce and Industry of Cyprus, 2000 https://www.youtube.com/watch?v=-zWQAdEean8&t=36s
- Interview of architect Petros Lapithis on The use of solar energy in everyday life to protect the environment and human health. https://www.youtube.com/watch?v=RfhEbHL78Oc&t=2s
- Architect Petros Lapithis interview on Architecture and Bioclimatic Design in Cyprus. Fred TV -2000 https://www.youtube.com/watch?v=O8O_Kjo6zqY&t=5s
- Interview of architect Petros Lapithis on The need of Bioclimatic Architecture. TV Paphos -19/8/1998. https://www.youtube.com/watch?v=BHJ0UrNIKME&t=6s

Videos on Experimental Solar House:

- Interview of architect Petros Lapithis on Solar Architecture in Cyprus. XLab: Stin Priza. 19.2.2008. https://www.youtube.com/watch?v=SxwVdKZx3hU&t=6s
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Videos on Agios Andreas house:

- Video Existing Building: https://www.youtube.com/watch?v=3NQKykhYflk

Bioclimatic architecture is a viable energy-saving concept which can be applied in the context of Cyprus. This book investigates the influence of passive solar systems in traditional and contemporary architectural forms. It focuses on the typical Cypriot family house and aspires to support the development of a specific regional, local architecture, which is sensitive to both energy use and climatic conditions.

A crucial argument is whether environmentally responsible architecture should be regarded as a specialisation within architectural education or whether its entire spectrum should be taught as a science and art that is equally accountable to man and the environment. This begs the question: Shouldn't architecture always be environmentally responsible?

Through a compilation of both the author's and his student's bioclimatic architectural designs, the book addresses bioclimatic design from a practical and academic approach.

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